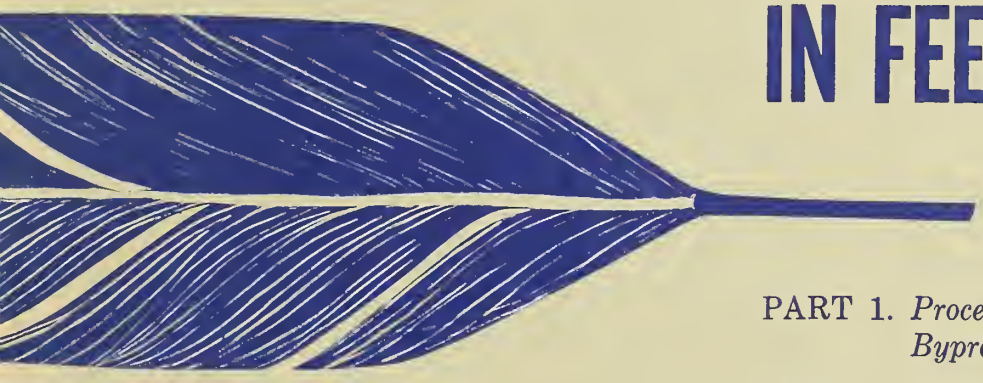
PROCESSING OF POULTRY BYPRODUCTS AND THEIR UTILIZATION IN FEEDS



PART 1. *Processing of Poultry Byproducts*

PART 2. *Utilization of Poultry Byproducts in Feeds*

Utilization Research Report No. 3

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service

Processing of Poultry Byproducts and Their Utilization in Feeds

Part I. Processing of Poultry Byproducts

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INTRODUCTION

The trend in poultry processing toward centralization and production of ready-to-cook-or-serve products has placed increasing emphasis on waste disposal and recovery of byproducts. Some of this centralization has resulted from building high-capacity processing plants to take advantage of mass production methods, but a great part has resulted from concentration of plants within certain areas. While this centralization has intensified the problem of disposal of poultry wastes, it has been at the same time a strong factor in the development of poultry byproducts, because the amount of waste has been sufficient to attract rendering concerns. The availability of poultry wastes in geographical regions and the means used for their disposal or utilization in byproducts were described in detail by Kahle and Gray in 1956 (*36*).[1]

The wastes from poultry slaughtering are segregated at different points along the processing line. Blood, then feathers, and finally offal (viscera, heads, and feet) are collected separately and can be processed into blood meal, feather meal, and poultry meat-scrap meal, respectively. Processing and marketing poultry blood meal and meat-scrap meal have not presented particularly difficult problems to the rendering industry, because these materials are similar to those from other animal sources. Because of costs of disposal, however, feathers were an economic liability until a method for converting them into a friable meal came into use.

While there was little question regarding the utility of byproducts from offal and blood in animal feeds, the same was not true of feathers or feather meal. It was known, for instance, that keratinous proteins such as feathers, horn, hoof, and hair were of little or no nutritional value because of lack of digestibility in their natural state. It was therefore necessary to show that feather meal is digestible and has some nutritional value before it could be accepted for use in feeds. For this reason and because it is potentially the principal byproduct from poultry processing, the major portion of this bulletin is devoted to feather meal.

The bulletin is presented in two parts. Part I deals primarily with the effects of processing variables on the chemical and physical properties and is based largely on work conducted at Western Utilization Research and Development Division, U.S. Department of Agriculture. Part II is concerned with the effects of the same variables on nutritional properties and with overall nutritional evaluation. It was prepared at Ohio State University and is based in part on work conducted there and at Clemson Agricultural College.

[1] Italic numbers in parentheses refer to Literature Cited p. 34.

Part I. Processing of Poultry Byproducts

By John Gorton Davis, Edward P. Mecchi, and Hans Lineweaver

Volume and Recovery of Byproducts

More than 8 billion pounds of poultry (broiler, chicken, and turkey) were processed in 1959 (*68*, *69*). Yield estimates of Lortscher et al. (*40*) show that recoverable byproducts from this amount of poultry would be 507,000 tons of feather meal, poultry byproduct meal, blood meal, and grease. Table 1 shows the disposal of raw processing wastes in 1955 as calculated from data collected by Kahle and Gray (*35*, *36*) and by Faber.[2] Table 2 gives the estimated yields of processed byproducts (*40*) and the amounts that would be available if the total supply could be utilized.

The percentage of the available byproducts that goes to renderers and feather dealers (62 percent) is the principal portion from which the poultry processor may receive an appreciable return. Calculations based on the data of Kahle and Gray (*40*) indicate that this return could amount to about one-half of 1 percent of the value of the poultry slaughtered. Utilization by farmers generally represents little or no return beyond reducing disposal costs. The 18 percent of the total byproducts that is not recovered is largely from small or inaccessible operations.

[2] Unpublished data.

Table 1.—*Recovery of poultry byproducts, 1955* [1]

Byproduct	Recovery by—			Total recovery
	Renderers	Farmers	Feather dealers and other	
	Percent	*Percent*	*Percent*	*Percent*
Offal	76	14		90
Feathers	46	25	5	76
Blood	31	13		44
Percentage recovered of total available	60	20	2	82

[1] More recent data are not available. The continuing trend toward increased centralization of poultry processing makes it probable that the proportion of byproducts utilized by renderers is materially greater than that shown. (Data were obtained from Kahle and Gray (*35*, *36*), along with unpublished data of F. L. Faber.)

Table 2.—*Processed byproduct yields and potential supply from principal types of poultry*

[Live-weight basis, 1958 production]

Poultry type	Processed byproduct yields (*40*)				Live weight (*69*, *72*)	Potential byproduct supply			
	Feather meal	Byproduct meal	Blood meal	Grease		Feather meal	Byproduct meal	Blood meal	Grease
	Percent	*Percent*	*Percent*	*Percent*	*Million lbs.*	*1,000 tons*	*1,000 tons*	*1,000 tons*	*1,000 tons*
Broiler	5. 50	5. 16	0. 78	0. 64	5, 431	149	140	21	17
Fowl	5. 50	4. 27	0. 67	3. 17	1, 516	41	32	5	24
Turkey	5. 9	4. 17	0. 78	0. 83	1, 334	39	28	5	6
Total					8, 281	229	200	31	47

Utilization by Renderers

The greater utilization of offal than of blood or feathers by renderers is primarily due to their ability to handle poultry offal in combination with similar material from other sources, so that even though the amount available does not justify separate processing, it can be utilized for tankage or meat scrap. Feathers must be treated with steam under pressure to make them friable and digestible, whereas offal is usually processed at atmospheric pressure. The processing required for feathers is generally considered too rigorous for offal, since it may result in some loss of nutritional quality and in greater amounts of fines in the expressed fat. Only under special circumstances would feathers, offal, and blood be processed together. (See p. 9.)

The collection and processing of blood by renderers is only incidental to the handling of offal and feathers. It is difficult to collect sufficient blood in the short time before decomposition begins to justify processing; therefore, only the largest poultry processing plants, or those in heavy production areas, can hope to obtain a return from collection of blood. When blood is collected in smaller plants, it is usually because of restrictions on flushing it into the sewers.

Washed Offal

Recently (*1*), equipment has been developed for grinding or mincing poultry offal, washing to remove dirt and intestinal contents, and centrifuging to remove excess water. Since freshness and freedom from odors are among the advantages claimed for the product, the operation would be best carried out in the poultry-processing plant, although it could be done in a rendering plant if provision were made to prevent decomposition of the raw material. The product contains about 18 percent of protein, which is more than 90 percent digestible, and 72 percent of water. The remainder is made up of fat and ash.

Because of its high water content, the product is perishable unless frozen or canned, so that it is not suitable for use in the usual dry-feed mixes. It is, however, suitable for use by mink ranchers and pet food manufacturers and appears to be well accepted in these markets. The development of the product is of such recent origin that little information is available on volume, size of potential market, or return to the processor.

Farm Use of Byproducts

Disposal of poultry processing wastes to farms is most prevalent in rural areas where other means are not available. Feeding of cooked poultry offal, sometimes including blood, to swine is a well-established practice in some localities. Health authorities require cooking of the offal to kill any parasites and disease organisms that may be present, and it is also desirable as a means of retarding the normally rapid decomposition of the offal. Mobile cookers are sometimes used, so that the offal can be picked up at the processing plant and cooked en route to the farm. Farmers may pay for the offal used as hog feed, but when they take all the wastes, it is more often considered that the offal pays for disposal of the feathers. There are, of course, many possible arrangements between processors and farmers, but generally the most important item to the processor is dependable removal of the wastes at minimum cost. Daily removal from the plant is generally required as a sanitary measure because of rapidity of decomposition. Because of the seasonal nature of the farm workload, daily removal is probably the main difficulty in farm disposal.

Farm use of wastes, other than that part of the offal used for feeding, is almost entirely for soil improvement. The wastes are simply turned into the soil and provide plant nutrition as they are decomposed by soil bacteria. While offal decomposes rapidly, feathers are quite slow, so that their nitrogen becomes available over a considerable period. For this reason, feathers can also be effective as a mulch if covered sufficiently to prevent them from being carried away by the winds. Raw poultry wastes, with the possible exception of manure, are difficult to apply to growing crops because of the need for turning them into the soil and the tendency of the entrails to festoon over foliage when scattered. Also, in the case of food crops, such application is regarded by health authorities as equivalent to application of raw sewage. The best utilization of poultry wastes for soil improvement is therefore between crops or on land that is out of production.

It has been informally suggested that the productive potential of poor farmland could be greatly increased by its use for a time as a disposal field for poultry processing wastes. The increased value of the land could subsequently be credited against disposal costs. The feasibility of such procedure would require special circumstances, the most important of which would be access to appropriate land and lack of rendering services.

Bedding and Other Purposes

The use of feathers as bedding and filling material is the only nonagricultural use for poultry byproducts of any importance at present. Since only the body feathers are used for this purpose, they are kept segregated from the large flight feathers of the tail and wings. They should also be washed and dried soon after picking to prevent bacterial decomposition, which causes persistent odors. Subsequent processing includes further washing and drying, cleaning, and separation of fractions by air flotation and blending of

various types for specific purposes (*30*). Some of the larger feathers may also go through a crushing process to break down the stiffer portions.

Chicken feathers have been displaced from this market to a large degree by synthetic fibers and foams. There is, however, a considerable demand for waterfowl feathers because of their exceptional resilience and insulating value. Most of those available at commercial poultry-processing plants are recovered and utilized in such items as pillows, sleeping bags, and quilted cold-weather clothing. In 1956, waterfowl feathers sold for about $1 per pound (*36*).

Other nonagricultural uses of feathers are of negligible importance. Shredded feathers are occasionally used in insulating types of wallboard, and various selected feathers are used for millinery trimming, feather dusters, fishing flies, toys, and novelties. Fibers from regenerated feather protein have been produced on a pilot-plant scale in a rather wide range of sizes and found usable—but apparently not economically feasible—for textiles, filling materials, and bristles. Mechanical processing of feathers into a form suitable for felting or woven fabric has been attempted, but so far has not been successful.

History of Feather Processing

During the early development of the poultry-processing industry, the greater part of the production was uneviscerated or "New York dressed," and feathers and blood were the principal wastes. For some time, these wastes were spread on adjacent land or hauled out to dumps. Unless the feathers were covered, they would blow when dry and develop offensive odors when wet. Even when the feathers were spread and covered, conveniently accessible land soon became overloaded to the point where old feathers were simply being covered with new feathers.

Studies on the development of visceral off-flavors in New York dressed poultry, begun about 1940 (*29*), eventually led, along with convenience and esthetic consideration, to its almost complete replacement by eviscerated ready-to-cook poultry. The resulting availability of offal attracted the attention of renderers, to whom it was a familiar type of raw material for byproduct meal and grease. Since feathers were also available in large quantity and were known to consist primarily of protein, these renderers became interested in them as a possible source of feed protein or fertilizer nitrogen. The U.S. Department of Agriculture, because of its interest in the utilization of agricultural products, likewise became interested in the potentialities of feathers and initiated a research program at its Western Utilization Research and Development Division with the object of developing new uses for feathers.

Artificial Fibers From Feathers

The initial objective of the U.S. Department of Agriculture research program was to develop products of enough value so that the poultry industry could realize some return from feathers. To this end, methods were developed for preparing dispersions of feather keratin from which fibers could be spun.

The first such method (*41*) was to extract the feathers with a hot, concentrated anionic detergent solution, such as an alkylbenzene sulfonate, containing sodium bisulfite, at pH 6.5. After drying and grinding, the keratin-detergent complex could be redispersed in water and extruded through a spinneret into a saturated magnesium sulfate solution at pH 1–2. The fibers were washed, stretched, and dried, then further stretched in steam and extracted with aqueous acetone to remove the detergent.

In this manner, about 80 percent of the feather protein could be transformed into fibers having a glossy sheen similar to some rayon fibers and a dry tensile strength that compared favorably with some natural and artificial fibers. The principal disadvantages were comparatively poor wet strength of the fiber and difficulty in obtaining economical recovery of the detergent. Also, if colored feathers were used, the color carried through to the finished fiber. The color problem is not so serious now as earlier because of the predominance of white poultry now being processed.

Further investigation led to the discovery and development of a method for solubilizing feather keratin in hot aqueous alcohols with the aid of a reducing agent such as sodium bisulfite. Fibers were produced from the solubilized keratin in a manner similar to that used for detergent protein dispersions. The advantages of this improvement were lower chemical costs and easier and less costly recovery of the alcohol due to its volatility. Because the alcohol could be removed by evaporation rather than by extraction, thicker fibers of a type suitable for bristles could be produced. The poor wet strength of fibers from both alcohol and detergent dispersions can be improved by stretching and by treatment with solutions of acidic formaldehyde or other protein hardening agents, but such treatment also results in embrittlement or loss of elasticity.

These developments looked sufficiently promising that commercial development was carried through the pilot-plant stage by a private concern. Because a part of the commercial interest had been based on wartime shortage of natural bristle

suitable for paintbrushes, and because of the interim development of other synthetic bristles, such as nylon, the program was shelved in 1956 without going into production and sales. Feather fibers for other purposes, such as upholstering filling, were also investigated but, at that time, were not found to have sufficient commercial promise.

In addition to the work on fibers, the possibilities of utilizing feathers in the manufacture of phenol-formaldehyde resin extenders (*11*), foaming agents of the type used for firefighting (*7*), sizes (*73*), set-retarding agents for plaster (*7*), and adhesives (*12*) were investigated. These potential outlets for feathers showed some promise; but it also became evident that they would be comparatively long-term developments and that, in the meantime, the feathers were accumulating at a rather alarming rate. For this reason, consideration was given to other means of utilization that could be put into practice more quickly.

Development of Feather-Meal Processing

While feathers had long found use as fertilizer and soil conditioner, the problems of perishability when wet and bulk when dry had prevented development of an appreciable market. Information on means of modifying the chemical and physical properties of feathers, developed concurrently with the above-mentioned investigations, indicated that it should be possible to solve these problems by treatment with steam under pressure, followed by drying and grinding. A simple process with minimum costs was necessary because of the competitive market in which the product would be sold.

Investigation of the variables involved showed that treatment of wet feathers, as received from the poultry processor, with saturated steam at 40 to 60 p.s.i. for 30 to 60 minutes yields a product that can be ground readily after drying and has satisfactory bulk density. It can be stored for extended periods in bags or bins without deterioration and remains free flowing. Overtreatment results in nitrogen losses and formation of gummy material that can foul the processing equipment. Undertreated feathers do not grind well, have low bulk density, and are less digestible than those adequately processed.

C. H. Binkley was responsible for the feather-meal-processing development at the Western Utilization Research and Development Division. He devoted special effort to developing a process readily adaptable to existing equipment in rendering plants so that trial runs could be made and production commenced with little additional investment, except as required to increase production capacity. At the time, the process appeared to have sufficient novelty to justify application for a public service patent which was made in February 1950. Shortly thereafter, a report (*7*) was prepared and made available to the public. It was instrumental in arousing the interest of rendering concerns and contributed significantly to the development of commercial feather-meal processing even though information brought out during the subsequent patent litigation showed that a number of people were aware of the feasibility of such a process and that at least one concern was actively engaged in a similar development.

Feather-Meal Patent Situation

With the filing of a patent application for the feather-meal process, it was discovered that at least one of the larger rendering concerns had also been active in developing a feather-meal process and had, in fact, filed application for a similar patent slightly more than a year before the U.S. Department of Agriculture application.

In accordance with U.S. Patent Office procedure, the applications of Edward J. Mayer (assigned to B–M–K Corp.) and of Charles H. Binkley and Harold P. Lundgren (assigned to public use) were declared to be in interference. Since Binkley and Lundgren were unable to prove prior reduction to practice to the satisfaction of the Board of Patent Interferences, the interference was resolved in favor of Mayer in 1954 and patent No. 2,702,245 was issued to him February 15, 1955. During the course of the proceeding, it was argued that the process was actually not patentable because of prior use, but since priority of conception and reduction to practice were the only points at issue, no decision was given on patentability.

By the time the patent was issued in 1955, a large number of firms were engaged in producing feather meal by treatment with steam under pressure. Twenty-eight of these processors filed suit in common in the U.S. District Court for the District of Delaware to have the patent declared invalid. On December 16, 1957, the court found the patent to be invalid, primarily because of prior knowledge and use. It was concluded that published information available in this country and others prior to the claimed date of invention (August 1947) was such that persons familiar with rendering practices could have predicted that treatment of feathers as described would yield a product useful for fertilizer or feed. In addition to 2 patents and 7 other publications cited against the patent, 26 individuals testified that prior to August 1947 they either had used steam under pressure to process feathers or knew that it could be done. Thus, since the process has been declared not patentable, it is in the public domain and may be used by any individual or concern desiring to do so.

Standards of Identity

The term "feather meal" is used in this bulletin to denote material which, in most States, would be officially designated as "Hydrolyzed Poultry Feathers." The definition, adopted by the Association of American Feed Control Officials in 1958, is as follows (*4*):

> Hydrolyzed Poultry Feathers is the product resulting from the treatment under pressure of clean, undecomposed feathers from slaughtered poultry, free of additives, and/or accelerators. Not less than 70 percent of its crude protein content shall consist of "digestible protein."

Since it was found that hydrolysis, in the most commonly used sense, appears to make no more than a minor contribution to the changes resulting from processing, the authors have used the term "feather meal" in this bulletin. The treatment would be more accurately described as "treatment with saturated steam under pressure," since pressure, heat, and water are all required.

A tentative definition for poultry byproduct meal was also adopted by the association in 1958 (*4*). This definition, which follows, is somewhat more explicit than that adopted in 1954:

> Poultry Byproduct Meal consists of the ground, dry-rendered clean parts of the carcass of slaughtered poultry, such as heads, feet, undeveloped eggs and intestines, exclusive of feathers, except in such trace amounts as might occur unavoidably in good factory practice. It shall contain not more than 16 percent ash and not more than 4 percent acid-insoluble ash.

Feather-Meal-Processing Requirements

The processing conditions mentioned previously were determined with small lots of feathers in laboratory equipment. Subsequent investigation under similar conditions has produced additional information on processing requirements for feather meal. When the *in vitro* digestibility in pepsin-hydrochloric acid under standardized conditions (appendix) was used as an indicator of degree of processing, the relationships shown in figure 1 and figure 2 were obtained. Variables such as size of load, rate of heating, and agitation rate may change the location of these curves, particularly in relation to the time scale, but should have little effect on their shapes.

Figure 1 shows the processing times required at the pressures indicated to obtain approximately 70-percent digestibility. The important feature of this relationship is the rapid increase in time required as pressure is reduced below 30 p.s.i., and the rapid decrease in time as pressure is raised above that point. Figure 2, which gives the relation between pepsin-hydrochloric acid digestibility and time at a pressure of 30 p.s.i., shows that digestibility increases rapidly until it reaches 65 to 70 percent, but then increases only slowly thereafter.

Figure 1 shows that it would be impractical to process feathers at pressures below about 25 p.s.i., because the time required becomes uneconomical in regard to equipment use. It is also evident that processing could be completed in minutes or even seconds at sufficiently high pressure. However, the difficulties of obtaining uniform heat transfer and the cost of specially built, high-pressure equipment discourage the use of pressure in excess of about 60 p.s.i. Good heat transfer is particularly important because the mass of feathers as loaded into the cooker has considerable insulating property even though wet. It thus requires time and agitation for heat to reach all parts of the load and provide uniform treatment. As treatment time decreases by use of higher pressures, the probability increases that portions of the load will be underprocessed. If time is increased to insure minimal treatment for all portions, some parts will be overtreated to the point of gumming or solubilization, which could result in appreciable loss of nitrogen and cause the material to become difficult to handle.

The fact that feathers can be processed at high pressure in a short time could be of interest in the development of a continuous processing machine. The size and capacity of such a machine would be proportional to the time required for the feathers to pass through, so that it would probably be desirable to use comparatively high pressure. So far as is known, no such machine is being developed, primarily because of the problem of feeding such a fibrous material into a vessel under pressure.

About the only situation where pressures of 20 to 25 p.s.i. for longer times might be practical would be where labor for loading and dumping could be made available only at certain times and processing could continue between times with minimum attention. Such an arrangement might be possible for a byproduct operation in conjunction with a processing plant.

Commercial Practice

In commercial practice, conditions vary considerably among processors, depending on their equipment, working schedules, and to some extent on operators' opinions. The primary consideration is to provide sufficient heat and moisture to break down the physical structure of the feathers. While it is possible to obtain satisfactory treatment in a very short time if pressure is high enough, a number of practical considerations limit the pressures that are used.

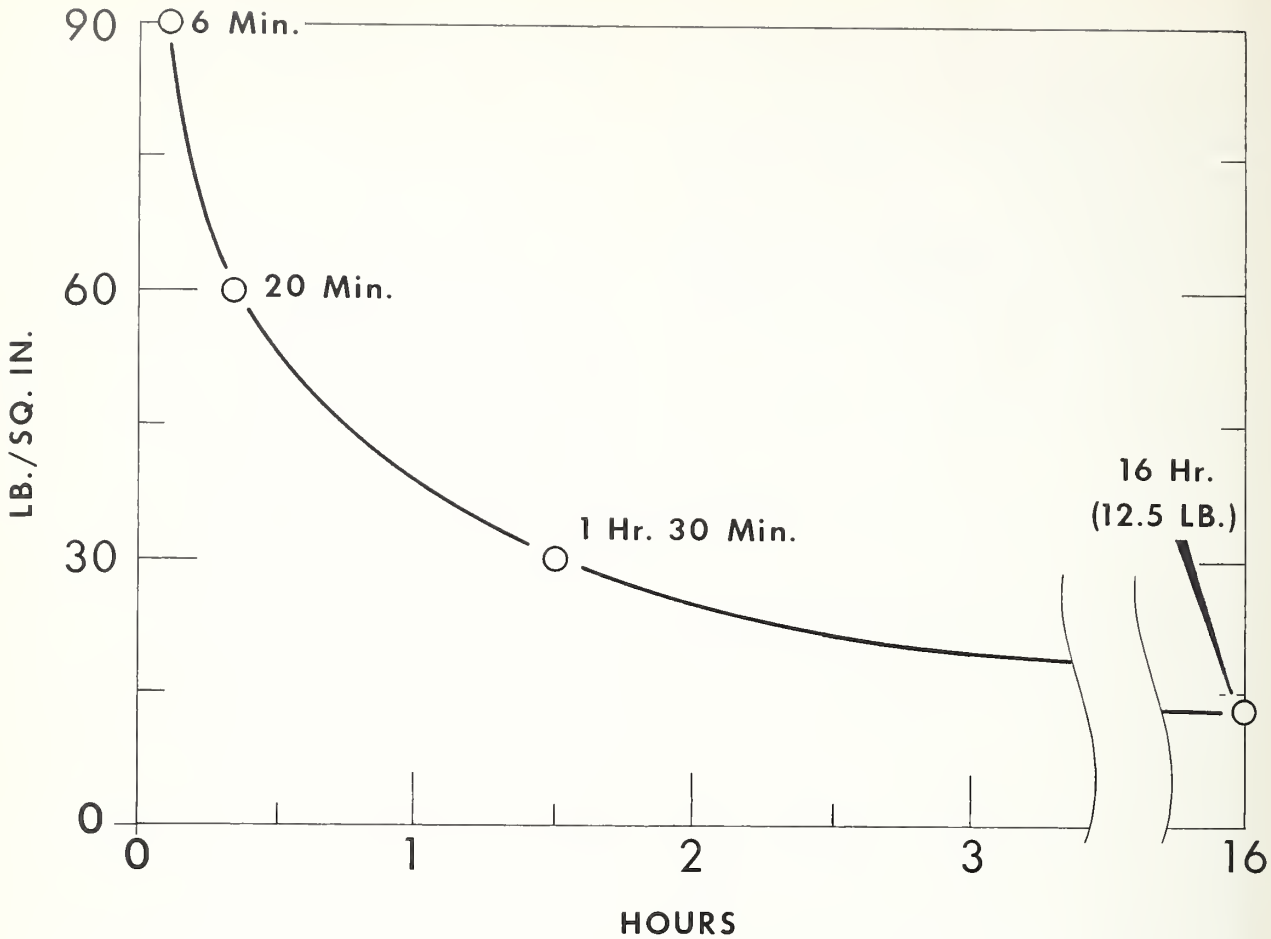

FIGURE 1.—Pressure and time of processing required to produce feather meal that is 70-percent digestible in pepsin-hydrochloric acid.

Most processors of feathers are renderers or have backgrounds in the rendering industry. They prefer familiar equipment that is readily available in standardized units and usable for other rendering operations. It is doubtful that the high cost of high-pressure equipment could be justified, as compared to costs of multiples of standard units with lower permissible operating pressures. Since the processing time is only a portion of the total operating cycle, it is apparent that unless comparable reductions can be made in loading and dumping time and in time to reach and reduce pressure, a point of diminishing returns is quickly reached when pressure is increased to reduce processing time.

Feathers are usually processed in dry-rendering cookers 4 by 7 to 5 by 12 feet in size. These cookers are steam jacketed, with horizontal shaft agitators and top and bottom openings for loading and dumping. They are generally operated with jacket pressures of 60 to 90 p.s.i. and internal pressures of 30 to 40 pounds. Internal pressures as low as 20 and as high as 60 pounds have been used, but most processors operate within the 30- to 40-pound range.

Processing time is 1 to 2 hours from the time the cooker is closed until it is opened to dump. Most of the variation is in the time required to reach and to reduce pressure. If the heat is applied to the jacket only, some water is commonly added to the wet feathers to make sure that enough is present for the processing reaction. It is not necessary, however, to add water if steam is injected directly into the charge. The latter practice has the advantage of requiring less heat and time to bring the charge up to temperature, since less is wasted in evaporating surplus water. Bringing pressure up quickly is important because little breakdown takes place until pressure is about 20 pounds (fig. 1). For the same reason, there is little object in holding the charge in the cooker after the pressure has been reduced at the end of the cycle. The critical point appears to be that the entire charge should be maintained at the equivalent of 30 pounds for at least 30 minutes.

In some operations, the charge remains in the cooker after pressure is released to effect partial

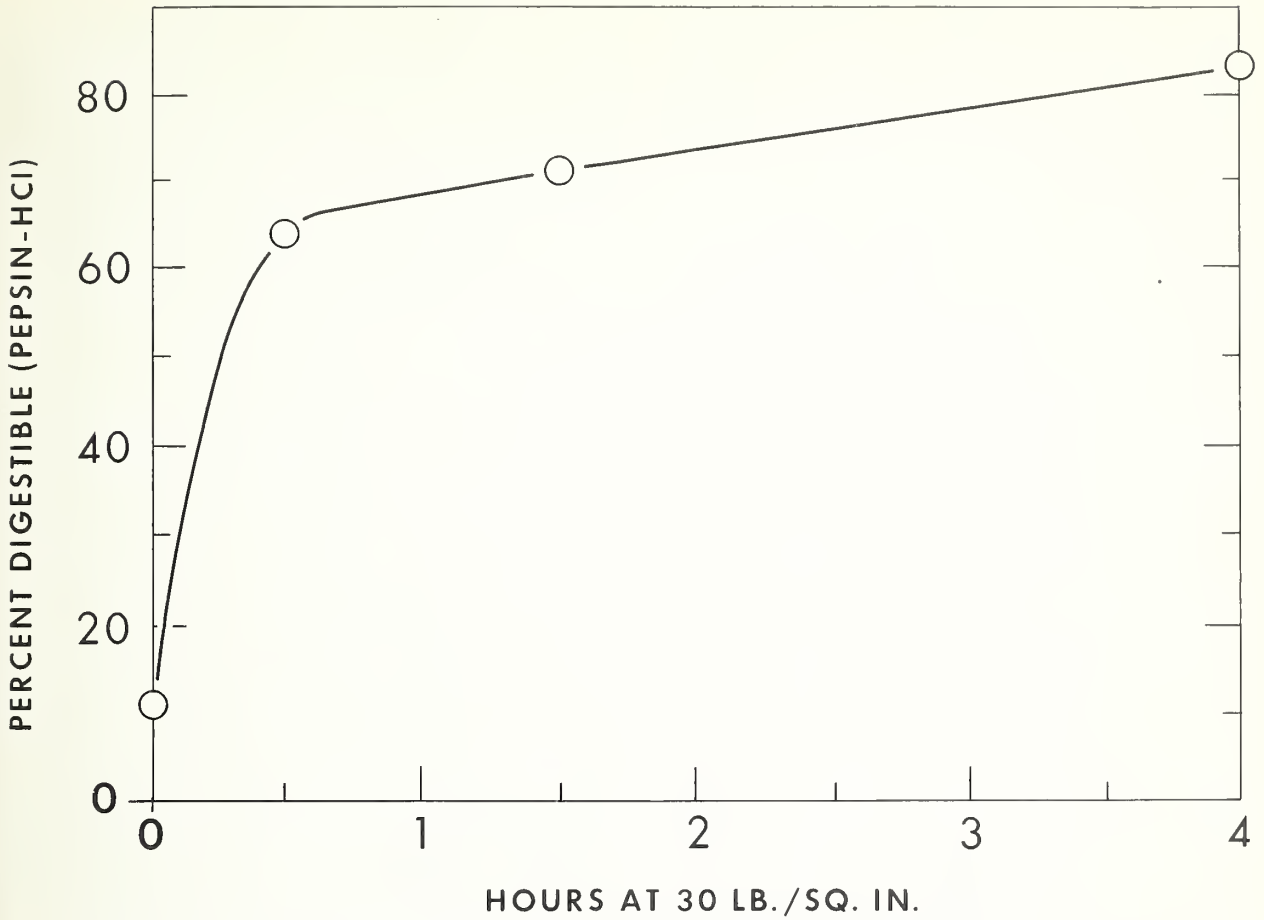

FIGURE 2.—The relation of pepsin-hydrochloric acid digestibility to time at a pressure of 30 p.s.i.

or complete drying. If the meal is finish dried in the cooker, the exhaust is usually discharged through a barometric condenser, so that the final stages of drying are accomplished at subatmospheric pressure. This drying practice is generally followed only in the smallest operations.

The most efficient operation is achieved by discharging the load from the cooker as soon as the pressure is released and feeding the output of several cookers to a steam-tube or direct-fired dryer. The direct-fired type is less expensive than the steam-tube dryer in both investment and operating costs, but is more critical to control with respect to reaching the desired moisture content and preventing darkening of the product due to overheating. Severe overheating can result in an appreciable loss of nitrogen, which represents a loss to the operator, but would otherwise have little effect on the performance or value of the product as fertilizer. At present, however, animal feeds provide the principal market for feather meal and for this purpose a lighter colored meal finds better acceptance. Since it has been found easier to produce light-colored meal consistently in steam-tube dryers, most of the more recent installations have been of this type.

The agitation to which the product is subjected during processing and drying breaks it up until little remains that is recognizable as feather. However, grinding and screening are desirable to improve uniformity of particle size. Screening also removes wing and leg bands, bottle caps, and other odds and ends. After processing and drying, the material has an almost glassy brittleness, which makes it easy to grind. Impact or hammer mills are effective and are most commonly used, since screening is accomplished in the same machine. The finished meal is usually sacked in 100-pound bags but may be sold in bulk. Along with other feed ingredients, feather meal and poultry byproduct meal are generally marketed through brokers.

Processing of Mixed Poultry Byproduct Meal

Interest in production of a mixed poultry byproduct meal from the natural proportions of feathers, offal, and blood stems from finding that a combined product would be more economical

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than separate products for small-scale operations (*40*). Byproduct recovery on a small scale is feasible when the operation is integrated with a poultry processing plant, so that services and labor can be shared. The principal attraction of such an arrangement would be the profitable production of byproducts or reduction of disposal costs. Freedom from dependence on an outside concern for removal of wastes could also be important.

Rendering operations are often associated with obnoxious odors, which should not be permitted in close proximity to food processing. Many of these odors arise from bacterial decomposition of materials being handled and could be prevented by sanitation and prompt handling, but the remainder are still objectionable. The most serious odors resulting from poultry byproduct processing are those due to the gaseous sulfur compounds evolved during feather-meal processing. While it should be possible to eliminate this problem by techniques developed for other industries, no engineering data are available and it remains a principal objection to processing poultry byproducts in poultry slaughtering plants.

The processing requirements and effects of processing for combined byproduct have not been investigated in detail, but it is possible to anticipate certain requirements from what is known about the components. Feathers will require the same amount of treatment whether separate or in a mixture. Offal and blood, however, require much less treatment and loss of nutritional quality might result from treatment similar to that given feathers. The procedure likely to give the best product, therefore, would be to treat feathers sufficiently first and then add offal and blood and continue until they were cooked and sterilized. The mixed product would also be dried in the cooker, so that the materials would be thoroughly mixed during the second cooking and subsequent drying. Since it would not be feasible to extract fat from the mixed product, grinding and sacking would complete the operations.

The composition of the combined byproduct meal, calculated from average composition of components, should be: protein, about 65 percent; fat, 10 to 15 percent; ash, 12 percent; and moisture, 8 percent. The fat content would depend on age and finish of the birds; the byproduct from younger birds would contain the least fat. As fat content increases, some difficulty with grinding might be anticipated, but the critical level would depend considerably on the type of mill used.

An experimental lot of meal prepared in the foregoing manner has given good growth as the only supplemental protein in a practical type of feed. (See section on nutritional properties in part II.) However, there has been little, if any, commercial production, so that the question of recognition and definition as a feed ingredient by the Association of American Feed Control Officials or by State control agencies has not yet been answered. Obtaining such recognition may be difficult in view of the general policy of opposition to recombination of byproduct materials that have once been separated. It would be necessary to determine the conditions under which such a product could be used in feeds in each State. In most States, however, it is permissible to use ingredients of this sort so long as they are adequately described on the label and have not been declared deleterious.

Laboratory Preparation of Feather Meal

As mentioned earlier, the initial interest in feather meal was due to its high nitrogen content and possible utilization as fertilizer. For this use, amount of nitrogen and rate at which it becomes available to crops are the principal considerations.

However, when interest began to develop in use of feather meal as a protein feed supplement, it became evident that more information on amino acid composition, particularly as affected by processing, and its availability to animals would be highly desirable. A research project to supply more information was undertaken by the U.S. Department of Agriculture at its Western Utilization Research and Development Division. While such information is highly important in regard to the value of a protein for feed supplementation, the ultimate evaluation must be obtained by feeding tests. Since the project would involve preparation of meals under various conditions, but without facilities for adequate feeding tests, cooperation was arranged with agricultural experiment stations for feeding test with experimentally prepared meals. The results and conclusions from these tests will be found following the discussion of the chemical effects of processing (p. 22).

The meals processed in the laboratory were prepared from feathers collected from a commercial plant, as soon as possible after picking. They were then washed thoroughly. Samples to be used as unprocessed control material were dried at approximately 140° F. and ground. Since wet feathers are much easier to handle for processing, those to be used for that purpose were not dried, but were frozen following centrifugation and thawed just prior to use.

The feathers were processed in a shop-built cooker constructed of a horizontal section of steel pipe 1 foot in diameter and 6 feet long. One end was closed with a welded cap and the other with a removable steel plate bolted to a welded flange. Three stainless-steel trays to carry the charge rested on interior supports. Piping included supply and exhaust lines, pressure regulator and gage, relief valve, condensate trap, and a fitting for attachment of a water pump vacuum. The ex-

terior and piping were insulated in a conventional manner. From 13 to 14 pounds of thawed wet feathers were spread uniformly on cheesecloth on the three stainless-steel trays, the cloth was folded over to prevent displacement by entering steam, and the trays were placed in the cooker.

Because no agitation was used, it was necessary to load the charge carefully so that the steam could penetrate quickly and uniformly. After the cooker was closed, the air was vented and the pressure raised as quickly as possible (1 to 3 minutes). The cook was timed from the time pressure was reached until it was released. After pressure was released, a vacuum was pulled for a short time to cool the charge for handling.

The feathers went into the cooker spread to a maximum thickness of about 2 inches and came out collapsed to a flaccid mat about a half inch thick. After drying at 140° F., the material was quite friable and could be ground easily in either a chopping mill or a hammer mill. Untreated feathers, on the other hand, could only be ground in a sharp and carefully adjusted chopping mill at a much lower rate. To obtain sufficient material for feeding tests, it was necessary to composite a considerable number of similarly processed batches. Most of the chemical analyses were carried out on portions of these composite batches.

The processing conditions were carefully selected to obtain maximum information with the minimum number of variables in order to keep the number of samples for feeding tests and analysis within practicable limits. Since it was anticipated that the information would have more practical than theoretical value, the limits of time and temperature were kept within the foreseeable useful range. Thus, the minimum processing treatment (30 minutes at 30 p.s.i.g.) was just sufficient to yield a product friable enough to grind readily and have reasonable bulk density. Feathers given less treatment would grind slowly with excessive power consumption and would be difficult to fill into the bags ordinarily used. The maximum processing treatment used (4 hours at 30 p.s.i.g.) is a condition where solubilization commences, so that in commercial practice nitrogen would be lost through the condensate trap unless special means were adopted for recovery. All processing pressures discussed refer to saturated steam.

The average yield of dry feather meal was 47 percent of the wet charge, or about 6 pounds. On a dry-weight basis, the yield was substantially 100 percent of both solids and nitrogen, with the exception of the overprocessed samples. Overprocessing (4 hours at 30 p.s.i.g.) resulted in a loss of about 2 percent of the solids and 8 to 10 percent of the nitrogen when the treatment time was more than twice that required to give 70-percent pepsin-hydrochloric acid digestibility. In normal commercial processing there would be a small variable loss of solids and nitrogen, due to the soluble material present in water on the feathers. This material was removed by washing the feathers used for the laboratory preparations prior to processing and is therefore not included in the data.

The extremes of processing used represent limits within which maximum economy can be found. It seems doubtful that feather meal would be marketed that had been processed to a greater or lesser extent except by accident. Underprocessed meal is easily recognizable, because it tends to be fluffy and has low bulk density. It could be given additional processing if such an accident occurred. Overprocessed meal is dark but not necessarily distinguishable from that made from colored feathers, so that it is less readily recognizable.

Figure 3 shows the effect of the processing treatments on color of the preparations. The differences are more pronounced in these samples than they would be for comparably processed commercial meals because of the low iron contamination. In commercial processing, a small amount of iron is picked up from the interior of the cooker and is converted to black iron sulfide by combination with part of the sulfur released during the processing reaction. The darkening due to iron sulfides thus tends to mask the darkening produced by processing. In addition to the progressive darkening that results from increased processing time at 30 p.s.i., figure 3 shows that slightly less darkening is caused by processing for a short time at high pressure than for a long time at low pressure.

The changes in microscopic appearance that result from processing are shown in figure 4. The original characteristic structure disappears progressively with increasing treatment until very little remains after normal processing. With overprocessing (4 hours at 30 p.s.i.g.), the original structure is completely gone, so that, after grinding, the material has the appearance of dark sand. Even though none of the original structural characteristics remain, an experienced feed microscopist can still recognize the material as feather meal in a feed (*13*, *14*).

In addition to information on effects of underprocessing and overprocessing, it seemed desirable to learn whether or not discernible differences developed between meals processed for a short time at high pressure or a long time at low pressure. Pepsin-hydrochloric acid digestibility (appendix) was the criterion for equivalency of processing. The time at each pressure was adjusted to obtain meal that was about 70-percent digestible in pepsin-hydrochloric acid. The processing conditions used and the digestibilities found for composited lots are shown in table 3. In addition to samples 1 through 7, which were prepared in sufficient quantity for feeding tests,

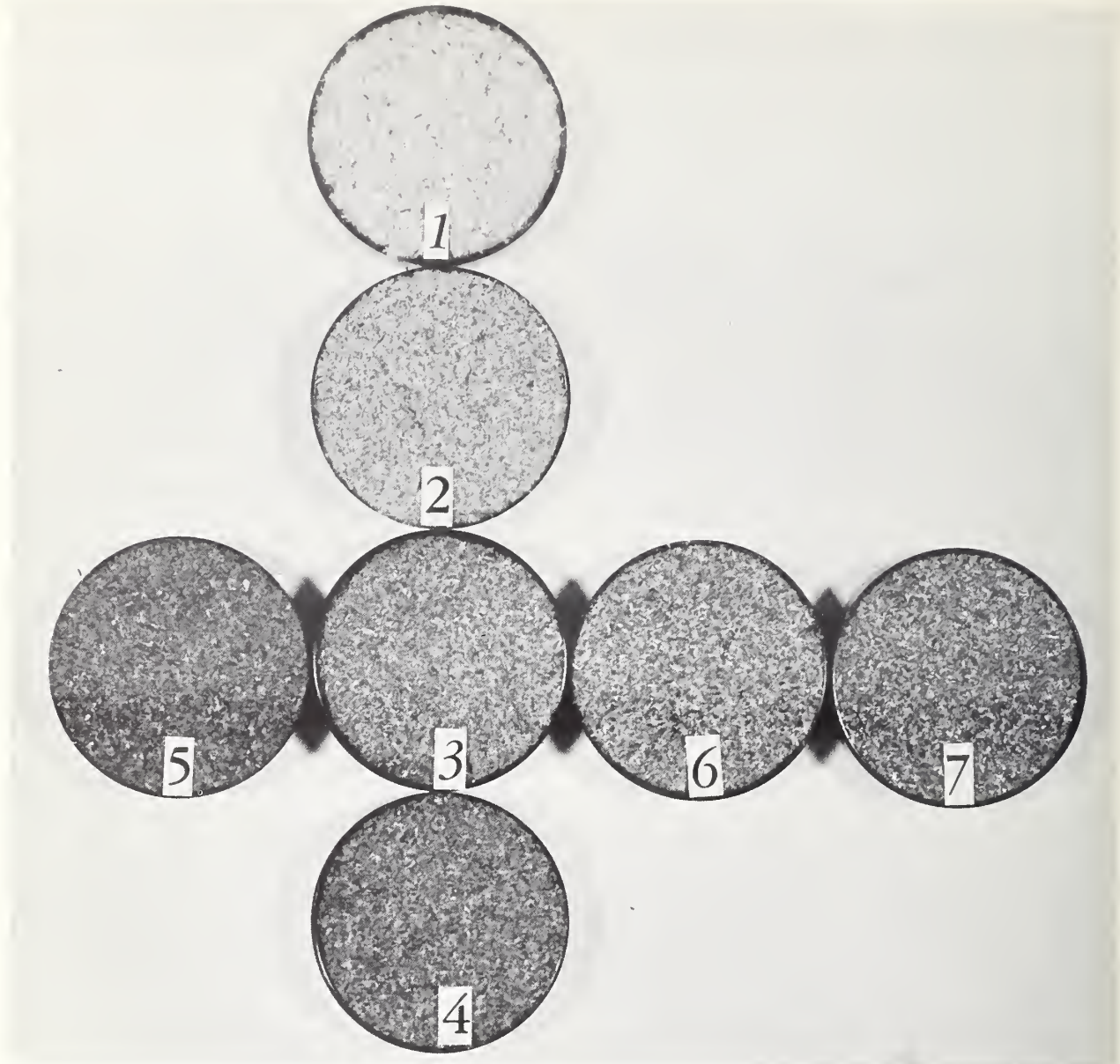

FIGURE 3.—Effect of processing on color of feather meal: (1) Ground feather, unprocessed; (2) 30 minutes at 30 p.s.i.g.; (3) 90 minutes at 30 p.s.i.g.; (4) 4 hours at 30 p.s.i.g.; (5) 16 hours at 12½ p.s.i.g.; (6) 20 minutes at 60 p.s.i.g.; and (7) 6 minutes at 90 p.s.i.g.

FIGURE 4.—Effect of processing on microscopic (50 X) appearance of feather meal: (1) Ground feather, unprocessed; (2) 30 minutes at 30 p.s.i.g.; (3) 90 minutes at 30 p.s.i.g.; and (4) 4 hours at 30 p.s.i.g.

smaller samples, sufficient for analysis only, were prepared to determine the effect of lime and of spoilage on amino acid composition. The samples were all prepared from chicken feathers. Samples of turkey feather meal were prepared for analysis only, since large amounts are available at certain seasons.

TABLE 3.—*Treatment and pepsin-hydrocloric acid digestibility of laboratory feather-meal preparations*

Sample	Processing conditions		Protein digestibility
	Time	Pressure	
		P.s.i.	*Percent*
1	0	0	16
2	30 minutes	30	64
3	90 minutes	30	71
4	4 hours	30	83
5	16 hours	12½	70
6	20 minutes	60	72
7	6 minutes	90	74

Quality Control of Feather Meal

Pepsin-hydrochloric acid digestibility (appendix) appears to be the best chemical method now available for determining the quality of feather meal, because it is most closely related to the nutritional value. This method, however, requires approximately 24 hours and also laboratory equipment that many processors do not have. Color, microscopic appearance, friability, and bulk density, on the other hand, are properties which, with practice, can be judged accurately enough to provide a good estimate of quality at the time of processing.

Figures 3 and 4 show the changes of color and microscopic appearance that occurred during the processing of laboratory samples. Similar changes occur during commercial processing. Color, of course, is influenced by original color of the feathers. If the feathers include a large proportion of dark feathers, such as bronze turkey feathers, color changes but little during processing. Also, sulfide is liberated during processing which can combine with iron from the equipment to form black iron sulfide and cause the product to be ex-

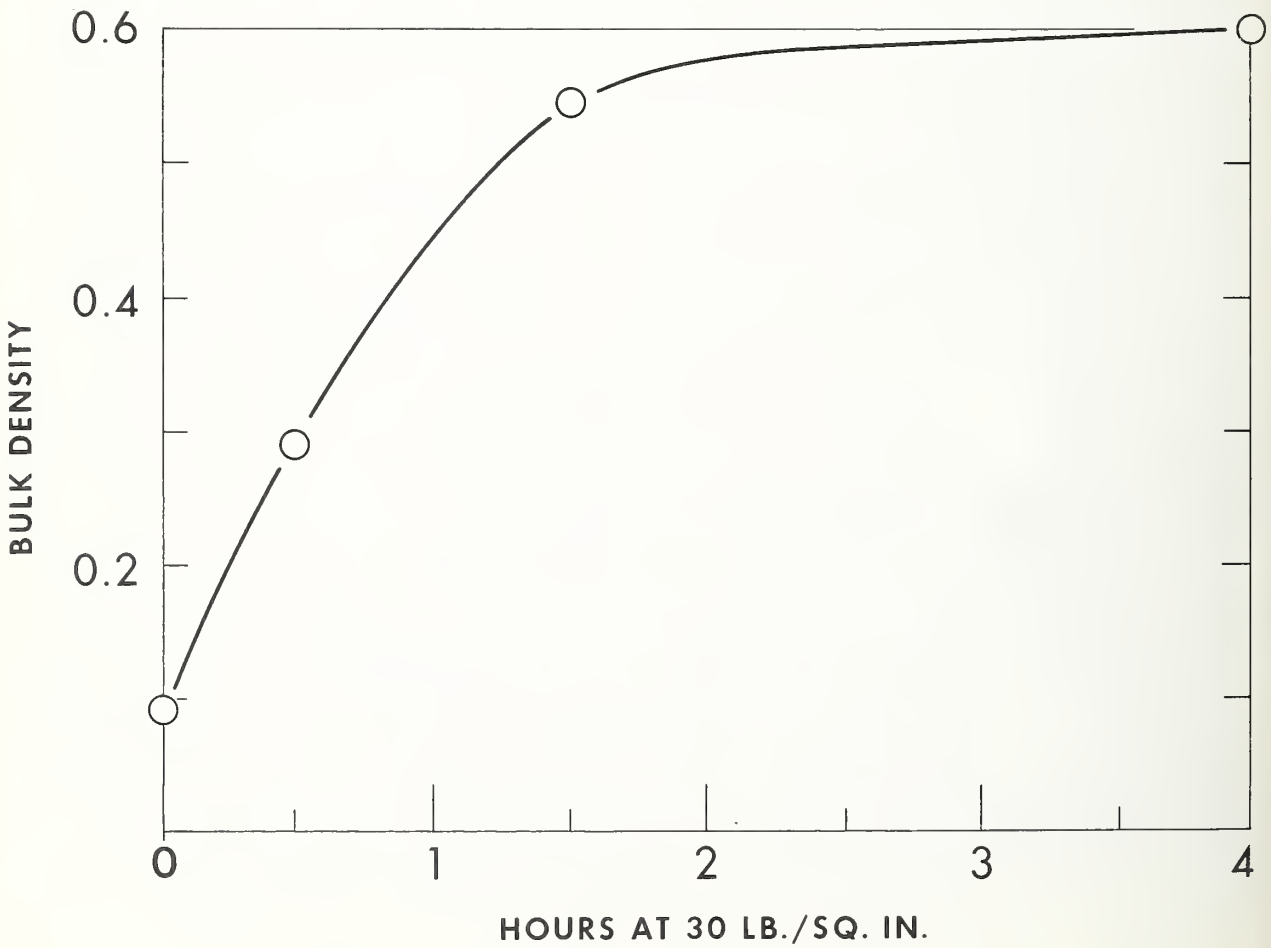

FIGURE 5.—Effect of processing on bulk density of feather meal.

cessively dark. Thus, while a light-colored product has almost certainly not been damaged during processing, a dark product has not necessarily been damaged, so that color should not be relied on too heavily as an index of quality.

Microscopic examination of the product should reveal no recognizably unaltered feather structure that would indicate underprocessing. Excessive fines could indicate overprocessing, but they would vary considerably with the grinding method. For this examination, a sample should be suspended in water containing a small amount of detergent. This breaks up the clumps so that the individual particles can be seen more readily.

The bulk density of feather meal appears to provide the most reliable quick estimate of quality. Figure 5 shows how bulk density increased as processing increased for a series of laboratory preparations. The curve is very similar to the pepsin-hydrochloric acid digestibility curve. This means that for particular operating conditions, it should be possible to establish a close relationship between bulk density and pepsin-hydrochloric acid digestibility, and by determining bulk density to obtain a good estimate of digestibility. The determination would preferably be made on the product as it comes from grinding, but could probably also be made on the dryer discharge. It is even possible that a determination on the cooker discharge could provide useful information.

The bulk density referred to here is simply the weight of a volume of meal divided by the weight of the same volume of water. The only apparatus required is a container of convenient size and a spring or platform scale. For instance, an ordinary bucket is tared, filled with water, weighed and the tare deduced. It is emptied, dried, and refilled with feather meal, joggled lightly, leveled off, and weighed. After deduction of tare, the weight divided by the weight of water gives the bulk density. In practice, this would probably be reduced to determining whether the weight of a level bucketful of feather meal was within acceptable limits.

Effect of Processing on Amino Acid Composition

The amino acid analyses of the laboratory samples and two commerical samples are given in table 4. These results, with the exception of those for tryptophan, were obtained by quantitative paper chromatographic methods adapted to this particular problem from methods available in the literature. It was necessary to use five chromatographic systems and one ion-exchange preliminary separation to obtain values for the essential amino acids. The nonessential amino acids and lanthionine were also determinable from the same series of chromatograms and are therefore included to give an essentially complete amino acid composition. In addition to lanthionine, one other ninhydrin-reacting substance produced during processing was observed on the chromatograms but was not identified. Details of the chromatographic procedures are given in the appendix.

All the amino acids except tryptophan were determined following hydrolysis with hydrochloric acid. The value for tryptophan (table 4) represents the best estimate it was possible to make from the colorimetric determination with p-dimethylaminobenzaldehyde (*62*, *63*, *64*). The difficulties experienced were apparently due to loss of tryptophan during alkaline hydrolysis in the presence of the large amount of cystine (*63*). The error in the determination could be as great as 50 percent. By careful standardization of technique, values were obtained that were reproducible within about 25 percent. Within this limit there was no detectable effect of processing on the tryptophan content even though the error in absolute value was greater.

The probable errors for amino acids other than tryptophan (table 4) vary considerably from one to another. The variations depend on such factors as sharpness of separation, intensity and compactness of the ninhydrin spot, and amount present. Thus, the values for phenylalanine, threonine, serine, and valine are the most accurate, with a probable error of less than 5 percent, whereas those for arginine, glycine, glutamic acid, and proline have probable errors of about 10 percent.

The results show that cystine is the only one of the 18 amino acids present in feathers that is significantly affected by processing with steam alone. The appearance of lanthionine in feather meal but not in feathers and the fact that the amount found approximates the loss of cystine during processing indicates that most of the cystine lost is converted to lanthionine. Furthermore, it has been known for some time (*33*) that alkali treatment of cystine-containing proteins such as keratins results in the formation of lanthionine from cystine, so that it is not surprising that the drastic conditions necessary for feather processing in the absence of alkali should result in a similar transformation. While the results also indicate some loss of glycine, the loss is barely greater than the experimental error. The amount remaining is still adequate nutritionally, and lack of glycine is seldom a problem in practical feeds.

The progressive changes of composition that result from increasing the severity of processing are shown in figure 6. The loss of cystine, rather than the amount found, is plotted to show the approximate parallel with the appearance of lan-

TABLE 4.—*Effect of processing variables on percentage*

Type of feathers and sample No.	Processing conditions		Argi-nine	Glycine	Histi-dine	Isoleu-cine	Leucine	Lysine	Methio-nine
	Time	Pressure							
Chicken		*P.s.i.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	0	0	6.6	9.2	0.6	5.2	7.6	1.8	0.4
2	30 minutes	30	7.5	9.1	.6	5.3	7.4	2.1	.4
3	90 minutes	30	6.8	7.7	.6	5.1	7.6	1.9	.4
4	4 hours	30	6.7	8.6	.5	5.4	8.1	1.9	.4
5	16 hours	12.5	6.7	7.4	.5	5.3	7.6	2.1	.4
6	20 minutes	60	7.2	8.5	.6	4.9	7.7	2.0	.4
7	6 minutes	90	6.1	8.8	.4	5.1	7.6	1.8	.4
8 [2]	90 minutes	30	6.2	8.6	.7	4.3	7.4	2.2	.4
9 [3]	90 minutes	30	6.4	9.3	.4	5.2	7.6	1.0	.5
10 [4]	90 minutes	30	6.9	8.3	.5	5.2	7.7	1.4	.4
Turkey									
11. Flight feathers	90 minutes	30	8.0	7.9	.9	4.6	7.4	1.9	.5
12. Body feathers	90 minutes	30	7.3	9.0	.6	4.8	8.2	1.2	.4
13. Flight feather meal	90 minutes	30	8.0	8.2	1.2	4.5	7.6	2.1	.5
14. Body feather meal	90 minutes	30	7.4	8.5	.7	4.4	8.3	1.5	.4
Commercially processed									
15. Sample A			6.4	7.2	.4	4.8	6.7	2.0	.4
16. Sample B			6.9	7.3	.4	4.2	6.5	2.7	.5

[1] Data on tryptophan are omitted. Results were erratic, averaging 0.4 percent. No processing effects found.
[2] 5 percent of lime added before processing.

thionine. When time and temperature were varied in a complementary manner to give equivalent pepsin-hydrochloric acid digestibilities (samples 3, 5, 6, and 7, table 4), there was little or no change in composition except for an increased conversion of cystine to lanthionine in sample 5, which was processed for the longest time at the lowest temperature (16 hours at 12.5 p.s.i.g.).

These changes occur slightly on the acid side of neutrality. The pH of an aqueous suspension of clean, untreated feather is between 6.7 and 6.8. After 30 minutes at 30 p.s.i.g., the pH of a suspension of the treated feather will be about 6.3 and after 4 hours it will be about 6.1. This change of pH is similar to other changes that occur; that is, the change takes place largely during the early stages of the process and continues slowly thereafter.

Preprocessing Putrefaction

Samples 9 and 10 (table 4) were prepared under the same processing conditions from freshly picked but unwashed feathers. Since they were not washed, the bacterial population was not changed and could thus be considered representative of that found in feathers used for commercial production of meal. Sample 9 was processed within approximately 2 hours of picking, while sample 10 was allowed to stand at room temperature for 1 week before processing. Considerable putrefactive odor developed, but the only change in amino acid composition of the meal was again an increased conversion of cystine to lanthionine. (The low result for lysine in sample 9 is almost certainly due to experimental error.) This increased conversion could lead to the simple conclusion that a microbiological conversion precedes chemical conversion during processing and that the result obtained is the sum of the two effects. It is, however, doubtful that this explanation is adequate. From what is known about the microbiological metabolism of cystine (*61*), it seems probable that it is reduced to intermediates which combine during processing to form the additional lanthionine found.

The putrefactive odors that develop in wet feathers before processing are the most serious consequence of excessive bacterial growth. They are objectionable not only to process operators but also to anyone else for a considerable distance downwind and have resulted in issuance of nuisance abatement orders. Loss of nutritional value can also occur through deamination and decarboxylation of amino acids. Some of the amines, such as histamine and tyramine, resulting from the decarboxylation reaction, also have undesirable physiological effects when present in excess.

The occurrence of vitamins and growth factors arising, in part, from bacterial growth is discussed in part II. From a practical standpoint, these can be considered only as fortuitous plus values. Lack of control over the type and extent of

of amino acids in feathers and feather meals [1]

Phenyl-alanine	Threo-nine	Valine	Cystine	Tyro-sine	Alanine	Aspartic acid	Glutamic acid	Proline	Serine	Lanthio-nine	Total N
Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
4. 8	4. 7	8. 3	8. 2	2. 8	4. 6	6. 1	9. 4	11. 3	11. 5	0. 0	15. 1
4. 7	5. 0	8. 2	7. 1	2. 8	4. 5	6. 5	10. 7	12. 0	11. 6	1. 3	15. 2
4. 5	5. 1	8. 3	5. 1	2. 9	4. 4	6. 0	10. 3	11. 1	11. 5	2. 1	15. 2
4. 5	4. 9	8. 2	5. 1	2. 8	4. 6	6. 0	11. 4	10. 9	11. 5	2. 6	15. 3
4. 8	4. 8	8. 1	4. 4	2. 6	4. 3	5. 9	11. 0	11. 1	11. 3	2. 7	15. 5
4. 8	4. 9	8. 1	5. 8	2. 8	4. 6	6. 5	11. 1	10. 6	11. 0	1. 7	15. 3
4. 6	4. 8	8. 5	5. 5	2. 8	4. 5	6. 4	10. 4	10. 6	11. 7	1. 8	15. 2
4. 5	3. 2	7. 7	3. 1	3. 5	4. 8	5. 9	11. 4	10. 6	7. 4	3. 7	13. 9
4. 9	5. 1	8. 2	6. 2	3. 0	4. 9	6. 6	10. 8	11. 2	12. 3	1. 4	14. 9
4. 9	5. 1	8. 3	5. 7	2. 9	4. 7	7. 1	10. 7	11. 2	12. 6	3. 3	15. 0
4. 9	4. 5	7. 9	7. 6	3. 1	4. 4	6. 4	8. 2	10. 1	12. 1	. 0	--------
5. 1	4. 6	8. 0	8. 3	3. 5	5. 1	6. 5	8. 2	10. 6	11. 3	. 0	--------
4. 9	4. 6	8. 1	5. 2	2. 9	4. 2	6. 9	8. 9	10. 3	12. 3	2. 0	--------
5. 1	5. 1	7. 7	5. 9	3. 3	5. 7	7. 8	7. 5	10. 6	12. 5	1. 6	--------
4. 5	4. 2	7. 4	4. 9	2. 4	4. 0	6. 2	9. 4	8. 7	10. 0	2. 0	13. 5
4. 3	4. 2	7. 3	5. 8	2. 7	4. 3	6. 2	9. 4	10. 4	9. 3	1. 2	13. 8

[3] Not fermented.
[4] Fermented.

bacterial growth prevents feather meal from being a reliable source for such factors.

Addition of Hydrated Lime

The addition of hydrated lime to feathers after picking has some effect on reducing odors. Because odor abatement has been a serious problem in urban areas, some meal has been manufactured from feathers to which lime has been added. Sample 8 of table 4, processed after addition of 5 percent of hydrated lime, shows its effect on the amino acid composition. The conversion of cystine to lanthionine was the highest found in any of the experiments. In addition, there were losses of 20 to 25 percent of isoleucine, threonine, and serine. Because the addition of lime creates an alkaline reaction environment (pH 8.5–9.0) in which arginine may be unstable, a loss of arginine was expected. While no such loss was found by the methods used in this study, a 40-percent loss of arginine in a commercial lime-processed feather meal has been shown by microbiological assay.[1] In this case, it is felt that somewhat more confidence should be placed in the microbiological result because of the greater specificity of the method.

The presence of alkaline materials during processing can also lead to another sort of loss that would not be apparent from the results given here. The amino acids of feathers are all of the natural or L-form. When they are heated with alkali there is up to 50-percent conversion to the unnatural or D-form. The D-form is the mirror image of the L-form and is chemically indistinguishable, so that chemical methods of analysis, such as were used here, do not measure the amount of conversion. However, living organisms do distinguish between the two forms and, in general, efficiently utilize only the natural L-form. Thus, this conversion, which is known as racemization, represents a loss of nutritional quality.

Turkey Feathers

There is more tendency to keep flight feathers segregated from body feathers when turkeys are processed than there is when chickens are processed. For this reason, the two types of feathers, and feather meals prepared from them, were analyzed separately (samples 11 through 14, table 4). Slightly larger amounts of arginine and histidine were found in turkey flight feathers than in turkey body feathers or in chicken feathers and more glutamic acid was found in chicken feathers than in turkey feathers. These differences are probably not significant, since they lie within the possibility of experimental error and are not supported by independent analyses (*10*). From the similarity of amino acid composition and lack of perceptible difference in processing requirements,

[1] G. F. Combs. Unpublished data.

600056 O—61——3

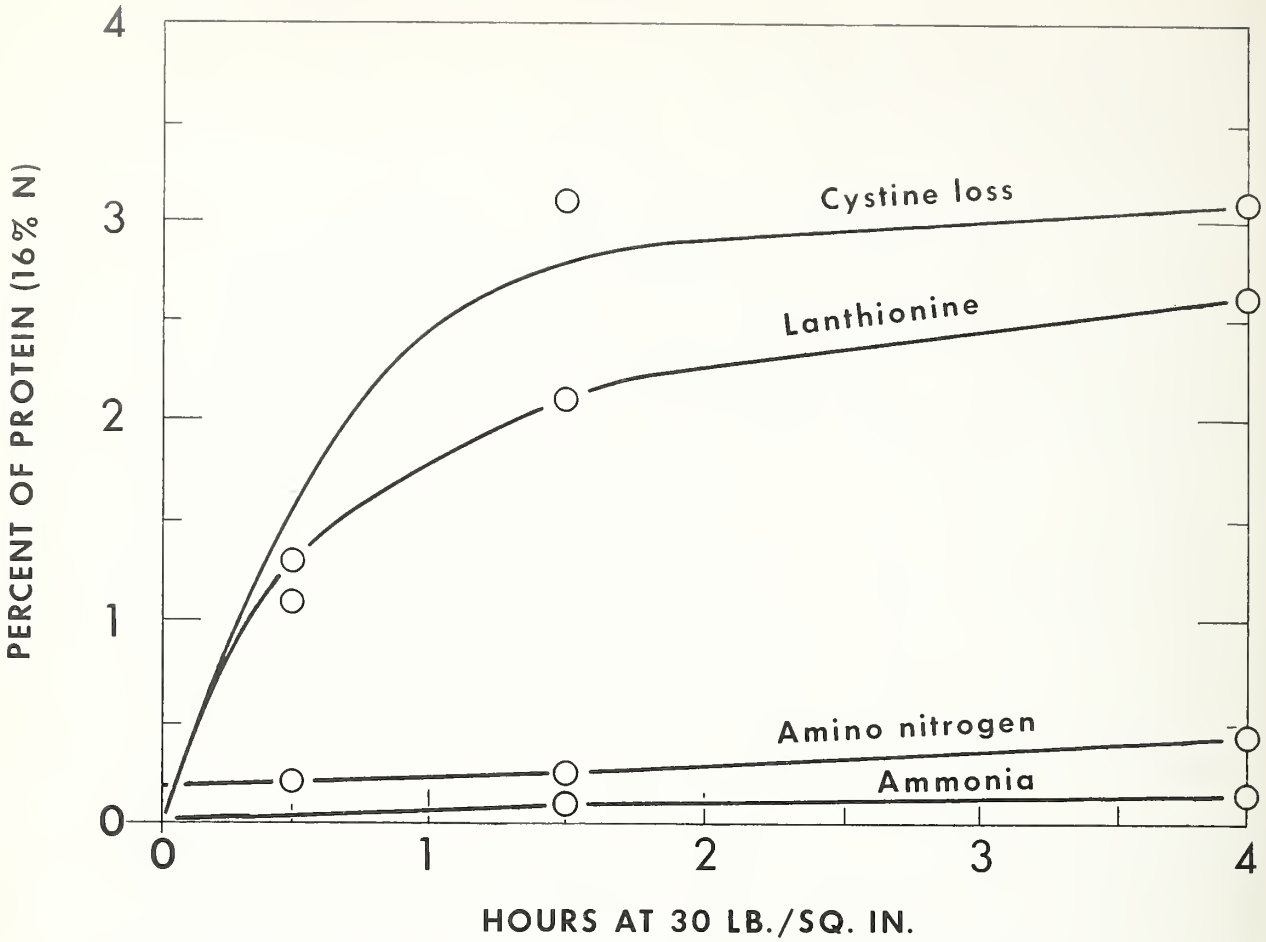

FIGURE 6.—Chemical changes in feather meal resulting from increased processing.

it would seem that turkey and chicken feathers can be utilized equally well for feather meal.

Commercial Feather Meals

While the two commercial feather meals (samples 15 and 16) are not necessarily representative, they were produced by two of the larger and more experienced firms in the field. Sample 15 was dried in a direct-fired dryer with special control equipment and sample 16 was dried in a steam-tube dryer. As can be seen from the amino acid composition, there is little or no significant difference between the samples. The difference in total nitrogen between the commercial and laboratory samples is largely due to the higher ash content of the commercial samples. When the laboratory-processed and commercial feather meals are compared on an equivalent nitrogen basis, amino acid compositions are similar.

Discussion of Feather-Meal Processing

Practical Aspects

Because the purpose of this report is to provide information regarding the utilization of poultry byproducts, primary consideration was given to the practical aspects of the problem. The data on chemical and physical changes resulting from processing of feathers with saturated steam under pressure show that the rate of change increases rapidly as steam pressure is raised above atmospheric pressure, but does not become rapid enough for most practical operations until it exceeds about 20 p.s.i. The data also show that, at constant pressure, the rate of change is most rapid initially and then slows markedly. This information, when used with that regarding bulk density, provides the processor with means of arriving at and controlling operating conditions best suited to his needs.

While bulk density may prove to be a convenient means of estimating adequacy of processing, it is not a measure of digestibility. The Association of American Feed Control Officials has adopted a minimum of 70-percent digestibility in pepsin-hydrochloric acid for "hydrolyzed poultry feathers" and the information on nutritional properties in part II indicates that this minimum should be maintained. It was found that a bulk density of 0.55 is equivalent to 70-percent digestibility for laboratory samples. However, various operating conditions will affect this relationship, so that correlation should be established under operating conditions prior to use of bulk density as a means of process control.

Mechanism of Feather Modification by Processing

The temperature requirements for feather processing, the conversion of cystine to lanthionine, and the rates at which the various chemical and physical changes occur provide information of theoretical as well as practical interest. This information, considered with X-ray diffraction data and published concepts of the structure of feather protein, provides evidence for a theory of the mechanism of transformation of feathers into meal. This is true even though most of the experiments were not designed with such a purpose in mind.

Since substantially all the proteins of which feathers are composed are classified as keratins, interpretation of the chemical and physical changes that result from processing requires some consideration of the structure of proteins in general and of keratins in particular. The following paragraphs include, in brief, those concepts that are relevant to this particular discussion. Fuller discussions of protein structure and classification and original literature citations are available in reference works (*20*, *25*).

Keratins, like other proteins, consist of chains of amino acids joined by peptide bonds. These bonds are formed by combination of the amino group of one amino acid with the carboxyl group of the next, and so on until as many as several thousand amino acid residues may be linked into a single protein molecule. In their native state, these molecular chains are arranged in an orderly manner, which is stabilized primarily by hydrogen bonds.

Hydrogen bonds can be broken by water, chemicals, or heat, leaving the protein chain free to unfold or unwind in a random manner. When this occurs, the protein loses its original native properties and is said to be denatured even though there is no change in composition. Coagulation, or reduced solubility, such as occurs when egg white is heated, or loss of enzymatic or other biological activity, is typical evidence of denaturation.

Keratins are differentiated from other proteins by their greater resistance to denaturation or other chemical or physical alteration and by higher proportions of cystine among their constituent amino acids. Since each end of the cystine molecule can be included in a protein chain by peptide linkage, it forms cross-links between protein chains or between different parts of the same chain. The greater stability of keratins, as compared to other proteins, is attributable to this cystine disulfide cross-link, so called because the central bond is between two sulfur atoms.

An additional important factor involved in the structure of keratins is the arrangement of the protein chains in relation to each other. X-ray diffraction patterns provide evidence that substantial proportions are arranged in regular parallel patterns, either of zigzag chains forming pleated sheets or of close-packed helices or of both (*16*). The helical conformation of the chains is such that they are extensible so that it is, in fact, possible to stretch certain keratin fibers to double their original length. When this is done, changes in the X-ray diffraction pattern indicate that the helical configuration has been converted to pleated sheets of zigzag chains. The unextended form is designated α-keratin and the extended, β-keratin. The X-ray diffraction pattern of unmodified feather protein is characteristic of β-keratin, indicating that the chains are extended even in the natural state.

The structure of native feather keratin may thus be visualized as extended chains of amino acids in parallel arrangement, bonded together by hydrogen bonds and cross-linked by disulfide bonds. While this is probably true to a considerable degree, it is oversimplified, in that somewhat greater uniformity is implied than is actually present. Ward et al. (*72*) and Schroeder and Kay (*60*) have found that parts of the feather have different amino acid compositions and that the translucent proximal tip or calamus differs most from the rest of the feather. Woodin (*78*) estimates that about 90 percent of the feather (without calamus) that is soluble in buffered 10M urea (0.1M $NaHSO_3$) consists of unbranched cyclic chains of about 90 amino acids. He considers these chains to be the monomeric units of the feather keratin structure and concludes that minor differences in composition between shaft and barbs may be due to varying amounts of heterogeneous protein comprising the remaining 10 percent.

The properties of the bonds responsible for maintaining the keratin structure are illustrated by the conditions used to prepare dispersions for production of synthetic fibers. A combination of reagents that acted on both the secondary hydrogen bonds and primary disulfide bonds were required (*41*, *42*). The cleavage of disulfide bonds was accomplished by a reducing agent such as bisulfite or monothioglycol. The hydrogen bonds

were dissociated by water and detergent or alcohol and the dissociation stabilized by combination of the detergent or alcohol with the protein, probably at the hydrogen bonding sites on the protein chain. Detergent or alcohol-salt water solutions alone only produce swelling and the reducing agents alone only soften the keratin.

The most important property of feather keratin relative to its utilization as a feed protein is its resistance to enzymatic digestion. This property can be attributed to the highly organized structure. Native proteins are usually more resistant to digestion by proteolytic enzymes than are denatured proteins (*54*). Since the process of denaturation involves the loss of internal orientation of the protein, it is not surprising to find that the highly organized structure of feather keratin is highly resistant to enzyme attack.

Effect of Processing on Keratin Structure

X-ray diffraction patterns show that one important effect of processing feathers with steam under pressure is loss of the organized structure originally present. The patterns in figure 7 show that the original organized structure cannot be detected even after the minimum processing treatment used. Increased susceptibility to enzymatic digestion (fig. 2) may also be taken as evidence of denaturation (*60*) or loss of structural organization.

Because the conditions required to cause the observed changes that result from processing are far more servere than those usually associated with protein denaturation reactions, it appears that cleavage of hydrogen bonds is not the limiting reaction involved. The disulfide cross-linkages between chains and the peptide bonds between amino acids are both necessary for the maintenance of the keratin structure. Therefore, if either or both of these types of bonds are broken, the structure could become disorganized.

The X-ray diffraction pattern, the enzymatic digestibility, and the product bulk density all show that the changes of properties are most rapid during the first 30 minutes of treatment at 30 pounds of steam pressure. The conversion of cystine to lanthionine, which requires breakage of the disulfide bond, is also most rapid during this time, providing evidence that at least one of the reactions that would be expected to yield disorganized feather keratin structure takes place. The rate at which this conversion occurs is similar to the observed changes in chemical and physical properties.

Hydrolysis of the peptide bonds between amino acids releases equivalent amounts of amino and carboxyl groups. As shown in figure 6, the amino

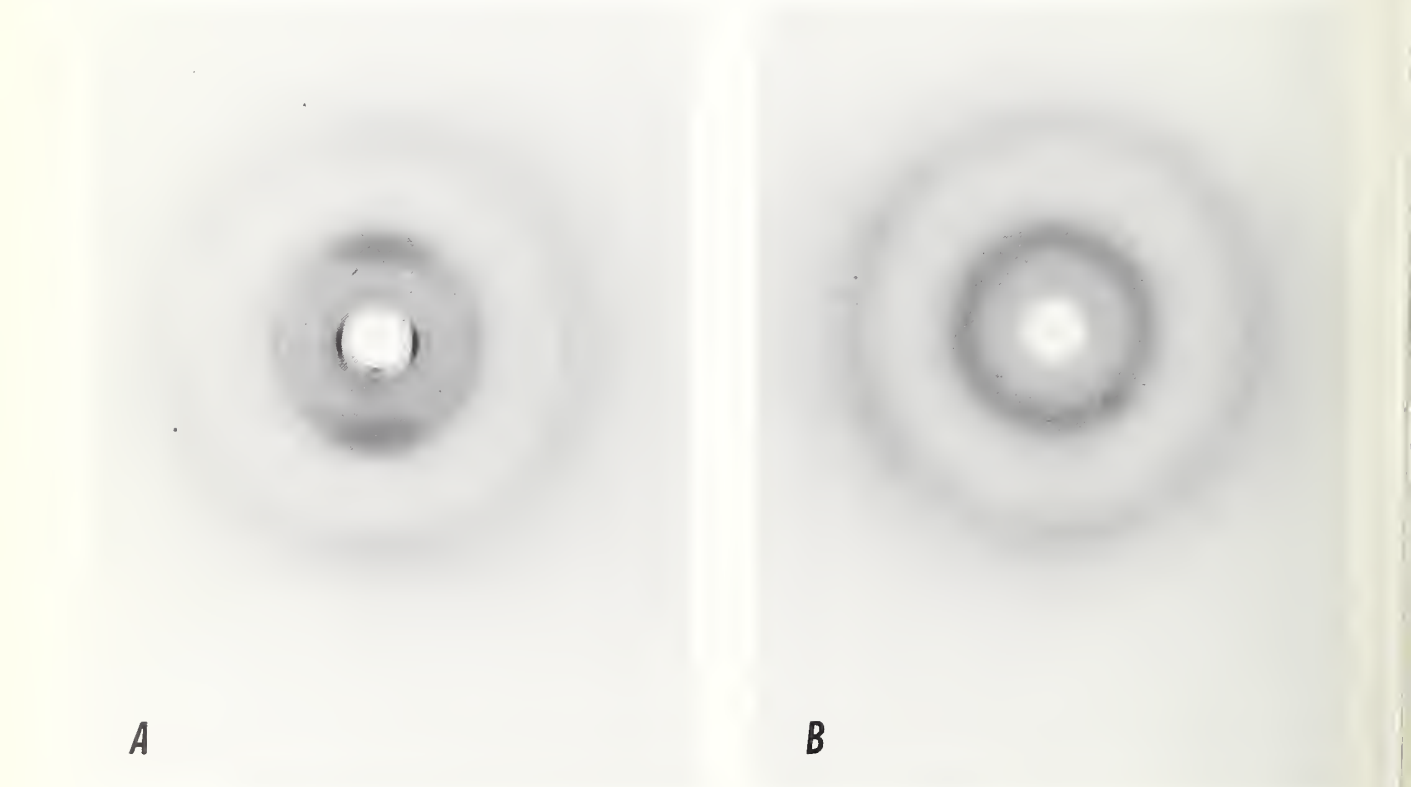

FIGURE 7.—X-ray diffraction patterns: (*A*), Feathers. Complex pattern showing high degree of molecular orientation. (*B*), Feather meal. Diffuse pattern showing loss of orientation after processing 30 minutes at 30 p.s.i.g.

nitrogen does increase during processing, but most of the increase occurs after the initial period just mentioned, indicating that cleavage of peptide bonds is involved only slightly, if at all, in the early rapid changes resulting from processing. However, as time at 30 pounds of pressure is increased beyond 30 minutes, the cleavage of peptide bonds may contribute to the further slowly increasing susceptibility to enzymatic digestion.

The conversion of cystine to lanthionine is a complex reaction. Presumably, cystine is first reduced to cysteine, part of which is then oxidized with the loss of sulfur to amino acrylic acid which can couple to the remaining cysteine to form lanthionine. Amino acrylic acid can be formed from serine under some conditions (*17*), but this apparently does not occur here since no loss of serine was observed in normal processing.

Lanthionine differs from cystine only in that the two parts are joined by one sulfur instead of two. It is equally capable of forming cross-links so that the total of cystine and lanthionine cross-links in feather meal is not much less than the number of cystine cross-links originally present in the feather keratin. It is therefore apparent that once cross-links have been broken and the structure has been permitted to become disorganized, reestablishment of cross-links is not sufficient to restore the original properties. Because of the disorganization of the structure, it is doubtful that the lanthionine cross-links connect the same parts of the protein chains that were connected in the original structure.

Conclusions

The market for byproducts of poultry processing as protein feed supplements is relatively steady and large enough to absorb the volume available. Hence it is the most satisfactory outlet at present. Much of the byproduct is now treated by rendering, but more specialized means, such as use of raw or washed offal in mink or pet food and feathers in bedding or novelties, offer opportunities for greater return in some cases.

When feathers are converted to meal with saturated steam only, the principal chemical changes are loss of cystine, appearance of lanthionine, and increased susceptibility to enzymatic hydrolysis. Arginine, isoleucine, serine, and threonine also may be lost if lime is added before processing. The physical changes include increased friability, loss of characteristic gross and microscopic appearance, and loss of molecular organization.

Pepsin-hydrochloric acid digestibility is the best method now available for estimating the adequacy of feather meal processing, but is too time consuming for good process control. There appears to be good correlation with the bulk density of the product, so that determination of bulk density may prove useful as a means of process control. Changes in color and gross and microscopic appearance give some indication of the extent of processing, but are not sufficiently critical for this purpose.

Part II. Utilization of Poultry Byproducts in Feeds

By Edward C. Naber

Poultry byproducts, except poultry grease, are used in feeds chiefly as sources of protein. Other growth factors that may be present are largely fortuitous and probably should be considered only as plus values. In this report, primary consideration is therefore given to quality of the proteins—that is, to their availability as sources of amino acids, and to their amino acid compositions. Combinations of poultry byproduct proteins with each other and with other proteins are also discussed in relation to their optimum utilization in feeds.

Types of Byproduct

Commercial feather meal (hydrolyzed poultry feathers) normally contains about 85 percent of protein, and laboratory preparations from cleaned feathers contain about 95 percent. Feathers could potentially supply well over half the protein available from poultry byproducts. For this reason and because of the particular problems of amino acid composition and availability, feather meal is given greater consideration here than are the other byproducts.

Poultry meat scrap (poultry byproduct meal) is made from offal (viscera, heads, and feet) by conventional dry rendering methods. Fat is sometimes recovered, if possible, but it may be added back to feather meal to reduce dustiness and add energy. Poultry meat scrap contains 50 to 60 percent of protein, the quality of which is comparable to that of meat-scrap products from other animal sources.

Poultry blood meal contains 65 to 70 percent of protein, which is a good source of supplemental histidine. The amount available, however, is small and often is insufficient to justify separate processing.

Data are included on a combined poultry byproduct meal made up from offal, feathers, and blood in their naturally occurring proportions. While only experimental amounts of this product have been produced, some interest has been shown in it because it could provide a single byproduct for small recovery operations which include recovery of blood. Such a product would contain about 65 percent of fairly good quality protein. Table 5 shows the average analyses of these products and the range of values found for a number of commercial samples.

Table 5.—*Gross composition of poultry byproduct meals* [1]

Byproduct	Crude protein		Crude fat		Crude fiber	
	Range	Average	Range	Average	Range	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Commercial feather meal	81. 8–89. 6	87. 0	2. 5– 4. 1	3. 5	0. 1–0. 4	0. 3
Laboratory feather meal	93. 1–96. 9	94. 9				
Poultry meat scrap	53. 1–57. 2	55. 2	13. 1–15. 7	14. 5	. 6–1. 5	1. 0
Poultry blood meal	65. 3–68. 6	67. 0	1. 0–11. 4	6. 2	. 2– . 8	. 5
Combined byproduct meal		63. 1		13. 2		1. 5

Byproduct	Nitrogen-free extract		Ash		Water	
	Range	Average	Range	Average	Range	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Commercial feather meal	0. 1–0. 4	0. 2	2. 1– 4. 2	3. 2	5. 6–11. 8	6. 5
Laboratory feather meal						
Poultry meat scrap	3. 9–8. 0	6. 0	16. 1–18. 5	17. 4	5. 8– 6. 4	6. 0
Poultry blood meal	0 –7. 0	3. 5	6. 1– 8. 8	7. 5	6. 7–26. 3	16. 5
Combined byproduct meal						7. 4

[1] Data pooled and averaged from references (*27, 50, 76, 77*), a personal communication from H. S. Kahle (1955), and this report.

Feeding of Keratins

Native Keratins

In the past, the keratin proteins have generally been considered to have little nutritive value because of their amino acid composition, structure, insolubility, and indigestibility. To this author's knowledge, the first attempt to study the nutritive value of native feather keratin was published in 1930 by Mangold and Dubski (*43*). In that study the secondary quills of white goose feathers were fed to owls, cats, dogs, and rats. Examination of feces showed some mechanical disintegration of the keratin in the cat and owl, but balance trials failed to show digestion in any of the experiments. In other studies, rats fed a diet deficient in cystine showed no growth that could be attributed to cystine furnished by ingested feathers.

Routh (*58*) found that powdered wool as the sole source of protein in an otherwise adequate diet was incapable of supporting growth in young rats. Tryptophan, methionine, histidine, and lysine were present in suboptimal concentration in this powdered keratin. Supplementation of the powdered wool diet with these amino acids resulted in moderate growth.

Routh (*59*) also fed finely powdered defatted chicken feathers to rats. Moderate growth occurred on a starch-sucrose-feather diet when supplements of tryptophan, methionine, histidine, and lysine were added. When any one of the four amino acids was omitted, growth failed to occur. When 5 or 8 percent of casein was used as a supplement to the diet instead of the four amino acids, growth rate was essentially the same.

Wagner and Elvehjem (*70*, *71*) showed that rats and chicks were able to utilize powdered swine hoofs as a source of protein for growth. The available protein in the powdered hoofs was, however, more adequate for the growing chick than for the growing rat. In addition, this keratin appeared to be a satisfactory substitute for meat scrap and fish meal in a practical chick starter ration. Newell and Elvehjem (*52*) found that powdered chicken feathers allowed only poor growth when fed to chicks and rats. However, the rates of growth obtained when powdered keratins were fed showed a positive correlation with the degree of subdivision of the keratin.

Baumane (*6*) reported that the sulfur in finely ground feathers was assimilated by the hen better than sulfur from inorganic compounds.

From the early work on the nutritive value of the native keratin proteins, it is apparent that serious amino acid deficiencies exist in feather protein. In addition, the digestibility of native keratins is poor because of their unique physicochemical structure. Also, finely powdered wool, feathers, and hoofs are slightly more digestible than these same materials in coarsely ground form.

Reduced Keratins

The keratin proteins can be solubilized by rather drastic physical or chemical treatment. Most chemical methods employ strong alkali with or without other chemicals that promote transformation of the keratin to a soluble form. Chemical transformations of this type result in irreversible disruptions of the amino acid chains within the protein. As a result, digestive enzymes probably find it easier to attack and release amino acids from the soluble protein molecule. On the other hand, alkaline treatment of protein usually results in destruction of individual amino acids.

Draper (*18*) solubilized feathers by treating them with a solution of sodium hydroxide and sodium sulfide. The dissolved material was then precipitated by neutralizing the mixture with hydrochloric acid. The protein residue was filtered, washed with water, dried, and reground for feeding tests. The treated feathers were fed to chicks and rats in rations composed largely of grains and grain byproducts. Unfortunately, no comparison of the chemically treated feathers with untreated feathers was made. However, a combination of corn oil meal and treated feathers gave better chick growth rates than either supplement did when fed alone. These results indicated that corn oil meal protein and feather protein had a complementary effect in supplying a better amino acid pattern for the chick. Rats fed the combination of treated feathers and corn oil meal, on the other hand, did not grow better than those fed only one of the supplements.

In another phase of his work, Draper (*18*) tested feathers that had been autoclaved for 2 to 8 hours under 15 to 50 pounds of steam pressure. Chicks fed the autoclaved feathers grew no better than those fed untreated ground feathers. In this trial, it is possible that any beneficial processing effects that might have existed were not found because of specific amino acid deficiencies that may have prevented differential growth rate expressions. Chicks fed the cereal diet without a feather supplement exhibited slower growth rates than chicks fed feathers as a supplement to the diet. This finding showed that feathers (autoclaved or not) were being used by the bird to a small extent.

Miyauchi and Tasaka (*48*) reported that autoclaving of feathers increased their digestion by the rat from 19 to 73 percent. The increase in digestibility was assumed to be due to the destruction of cystine bonds. These workers also showed that autoclaving of feathers and hair increased their susceptibility to enzymatic digestion by pepsin and trypsin.

Podhradsky (*53*) recently substituted poultry feather hydrolyzates for 22 and 44 percent of the protein in feed mixtures for chickens. Only small differences in performance of the birds fed

rations with and without the feather hydrolyzates were observed.

A very early report by the Kansas Agricultural Experiment Station (*37*) showed that hydrolyzed poultry feathers fed to laying hens improved egg production during one year but failed to do so during a second year. Just how the feathers were treated is not apparent from the report. Chicks fed the feather product did not grow as well as control chicks when the feathers replaced the animal protein products used in the control ration. Little was known about vitamins in the days of this report, and removal of animal protein products from the ration undoubtedly reduced the levels of several vitamins and minerals in the chick diet. Thus the findings are difficult to evaluate.

First Feeding Test of Commercial Feather Meal

The production of a friable meal from feathers was described in 1950 by Binkley and Vasak (*7*). Their method was essentially a wet cooking process in which feathers were treated with saturated steam at pressures of 40 to 60 p.s.i. for 30 to 60 minutes with continuous agitation. The cooked feathers were then dried and ground to produce a free-flowing meal. While Binkley and Vasak had nonfeed uses in mind, they did suggest the possibility that feather meal might be used as a feed component.

Wilder (*74*) reported the results of a chick growth test utilizing feathers processed by the method of Binkley and Vasak (*7*). From 3 to 6 percent of feather meal gave a growth response in chicks fed a corn-soybean oil meal diet. A combination of 3 percent of feather meal and 3 percent of blood meal fed as a supplement to the basal diet gave better growth than that obtained from the feather meal alone. The author suggested that blood and feathers together provided a better amino acid balance than either protein source used singly.

This experiment was probably the first to demonstrate actual growth responses to feather meal in a vegetable protein diet containing sizable quantities of soybean oil meal. Since soybean oil meal protein is rather complete in its amino acid pattern, except for methionine, it would appear unlikely that the growth response obtained from feather meal could be attributed to an improvement in the protein quality of the ration. A more probable explanation of the feather-meal growth response might lie in the ability of feather meal to furnish nonspecific alpha amino acid nitrogen or growth factors not related to its protein content.

Feather Meal as a Nutrient Source

Amino Acid Pattern

Because feathers are almost completely protein, a great deal of interest has been shown in the amino acid composition of feathers and feather meal. Microbiological assays on feathers and feather fractions have been published by Graham, Waitkoff, and Hier (*26*), and Ward, Binkley, and Snell (*72*). Feather meal processed by the method of Binkley and Vasak (*7*) has been analyzed microbiologically by Gregory, Wilder, and Ostby (*27*). Chromatographic analyses for amino acids in feathers and feather meals are included in part I (p. 16). The data available on amino acid composition of feathers are incomplete and subject to a considerable margin of error. Most amino acid hydrolyzates used in analyses contain breakdown products and unrecognized components that may or may not influence nutritive properties and component amino acids.

If one compares the amino acids in feather meal with the chick's requirement for each amino acid, it is possible to divide the essential amino acids into two classes. This classification is illustrated in table 6, which shows the percentage of the chick's amino acid requirement furnished by feather meal and other feedstuffs when each is the sole source of dietary protein. (It is assumed that the amino acids present in feather meal are completely digestible by and available to the chick.)

The first group comprises those amino acids present in feather-meal protein in quantities greater than required by the chick as a part of its protein intake. In this group are the following essential amino acids: arginine, phenylalanine, cystine, threonine, leucine, isoleucine, valine, and glycine. These represent the assets of feather-meal protein.

The second group comprises those present in feather-meal protein in quantities less than required by the chick. In this group are these essential amino acids: histidine, lysine, tyrosine, tryptophan, and methionine. This group represents the deficiencies of feather-meal protein.

Cystine falls into the first group because it is capable of sparing the methionine requirement, and the methionine content of feather meal is low. Tyrosine falls into the second group because it can replace part of the phenylalanine requirement, and the phenylalanine furnished by feather meal meets only the minimum necessary when sufficient tyrosine is present.

TABLE 6.—*Ability of certain feedstuffs, when used as the sole source of dietary protein, to supply the amino acid requirements of chicks*

Amino acid	Chick requirement as percentage of total protein intake [1]	Percentage of amino acid requirement provided by protein from—					
		Soybean oil meal [2]	Blood meal [2]	Poultry offal [3]	Feather meal [4]	Equal parts of blood, offal, and feathers	Blood, offal, and feathers in natural proportions [5]
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Arginine	6.0	120	70	115	110	98	108
Histidine	1.5	195	375	85	25	162	69
Lysine	5.0	135	175	265	35	158	117
Tyrosine [6]	3.5	115	65	90	75	77	79
Tryptophan	1.0	140	130	80	50	87	65
Phenylalanine	4.0	130	180	130	110	140	121
Cystine [6]	1.8	105	100	65	280	148	198
Methionine	2.3	75	50	115	15	60	49
Threonine	3.0	130	135	100	160	132	139
Leucine	7.0	115	170	135	115	140	125
Isoleucine	3.0	200	35	360	155	183	210
Valine	4.0	130	195	80	200	158	161
Glycine [7]	5.0	340	Trace	80	160	80	125

[1] Adapted from data for the amino acid requirements of the chick presented by Almquist (*2*).

[2] Calculated from data presented by Block and Bolling (*8*).

[3] Calculated from data presented by Acker, Hartman, Pemberton, and Quinn (*1*), and estimates.

[4] Calculated from average of data published by Gregory, Wilder, and Ostby (*27*), and data presented in the first section of this report.

[5] Based on yields of blood meal, feather meal, and poultry meat scrap reported by Lortscher, Sachsel, Wilhelmy, and Filbert (*40*).

[6] Essential for chick growth only under certain conditions. Phenylalanine can replace tyrosine when phenylalanine is present in quantities greater than those indicated as necessary. Likewise, methionine can replace cystine when methionine is present in quantities greater than those indicated as necessary.

[7] Data on glycine composition of feedstuffs, except feather meal, based on feeding tests.

When soybean oil meal protein is compared on the same basis as feather meal protein, methionine is the only essential amino acid for the chick that falls into the second group.

Analysis by microbiological or chemical methods reveals the quantities of amino acids present, but does not reveal anything about the digestibility and consequent availability of these amino acids from the protein to the animal. Nevertheless, the chemical and microbiological assays are valuable guides for the use of, and experimentation with, proteins of unknown nutritive value.

In Vitro Digestibility

Since digestibility of protein is closely related to its usefulness as a source of individual amino acids, interest has grown in methods that might predict the relative digestibilities of proteins. A chemical method described by Gehrt, Caldwell, and Elmslie (*22*) is based on the pepsin-hydrochloric acid digestibility method originally described by Almquist, Stokstad, and Halbrook (*3*). This method has recently been further modified by Elmslie (*19*). (See the appendix.) In this recent procedure, a defatted feedstuff sample is digested for 16 hours with a warm acid solution of pepsin under constant agitation. The percentage of digestible protein is calculated from the total crude protein before digestion and the crude protein remaining in the insoluble residue after digestion.

When pepsin-hydrochloric acid digestibility tests are applied to feathers and feather meals, a wide range of values is obtained. Unprocessed ground feathers yield from 10 to 20 percent of pepsin-hydrochloric-acid digestible protein. When feathers are processed under desirable conditions, digestibilities of 70 to 85 percent are obtained. Meals that have extremely high digestibilities are often undesirable because processing may have been overdone and individual amino acids may have been destroyed. Underprocessed feather meals yield digestibility values of less than 65 percent.

Feather Meal as a Substitute for Other Protein Feedstuffs

Since feather meal contains large quantities of protein, most attempts to study its nutritive value have been designed to evaluate it as a protein supplement. In such experiments, part of the protein in a diet of known value is replaced by feather-meal protein. Diets with and without feather protein are then fed to experimental ani-

mals. Growth and feed utilization are measured, and the results are compared. Most tests have been performed on growing chicks, although some tests, to be discussed later, have been with adult birds and other farm animals.

A number of investigators have found feather meal of good quality to be a satisfactory substitute for a fraction of the soybean oil meal protein in chick starting rations composed largely of soybean oil meal and cereal grains.

Wilder, Ostby, and Gregory (*75*) found that feather meals could replace 2.4 percent of the soybean oil meal protein in a chick starter containing a total of 20 percent of crude protein. The growth rate was improved further, however, when feather-meal protein was supplemented with an equal quantity of protein from either meat and bone scrap or blood meal. Lysine improved growth on diets containing 6.2 percent of protein from feather meal.

Naber (*49*) and Naber and Morgan (*50*) demonstrated that feather meal could replace one-fourth of the protein in a broiler ration containing large amounts of soybean oil meal and corn fortified with fish meal, dried whey product, minerals, vitamins, methionine, and antibiotic. Additional fish meal and poultry-meat-scrap supplements did not improve growth on the diets containing feather meal.

Lillie, Sizemore, and Denton (*39*) found that 5 percent of feather meal could be substituted for 5 percent of fish meal in a corn-soybean oil meal diet without detrimental effects on growth and feed efficiency of chicks. Working with laying hens, Harms and Goff (*32*) showed that 2.5 to 5.0 percent of feather meal supported normal egg production and hatchability when substituted for meat scrap in a corn-soybean oil meal breeder ration. Sullivan and Stephenson (*66*) reported that diets containing 2.5 percent of feather meal supported chick growth that was equivalent to the corn-soybean oil meal control diet. While the use of 5.0 percent of feather meal usually allowed normal growth, 7.5 percent of this feedstuff depressed growth rate. No supplemental methionine was included in the diets used in the work reported above. McKerns and Rittersporn (*46*) found that normal chick growth could be maintained when one-fourth of the protein from soybean oil meal was replaced by feather meal. This was true in diets containing either 16 or 24 percent of total crude protein. All the diets in this study were fortified with fish meal, meat meal, and liver meal.

In a series of three trials, Wisman, Holmes, and Engel (*77*) reported that feather meal was a satisfactory source of animal protein in broiler, grower, and layer rations when used to replace up to one-sixth of the crude protein content. When diets containing a suboptimal crude protein content were fed, feather meal appeared to be lower in protein quality than fish meal but comparable to soybean oil meal and meat scrap.

In addition to the detailed journal reports mentioned above, a small amount of information appears in abstracts of the Poultry Science Association annual meetings. These studies (*21*, *23*, *24*), which have not been reported in detail in journal literature, also show that feather meal can be substituted in chicken rations for soybean oil meal and to some extent for other animal protein feedstuffs. Finally, several semipopular reports (*31*, *56*, *65*) have also stated that feather meal can be used as a substitute for other protein supplements.

As a result of the work cited above, it is possible to draw certain conclusions: (*a*) Feather meal. when adequately processed, can be used as a substitute for as much as one-fourth of the crude protein in rations for growing chicks. This has been shown to be true of diets that are limiting in their total crude protein content. (*b*) Feather meal has given the best results in corn-soybean oil meal rations when these rations were adequately supplemented with sources of methionine. This is not surprising since corn, soybean oil meal, and feathers are all relatively low in this amino acid. The fact that soybean oil meal contains generous amounts of lysine undoubtedly accounts for the finding that substitution of feather meal does not create a lysine deficiency in diets high in soybean oil meal, except when large amounts of feather meal are used. (*c*) The protein quality of the basal ration is an important factor in determining the results obtained from feather meal use.

Amino Acid Supplementation and Availability

Early work by Routh (*59*) established that feather protein is deficient in tryptophan, methionine, histidine, and lysine for rat growth. These trials were conducted with ground untreated feathers. More recent studies have been concerned with the amino acid deficiencies of processed feather meals.

It is possible that the wet cooking of feathers under pressure could improve availability of some amino acids or destroy others particularly labile to heat. Consequently, recent studies (*51*) were undertaken to investigate amino acid deficiencies in diets containing both commercial and laboratory samples of feather meal. To accentuate the amino acid deficiencies of feather meal, only rations containing large amounts of feather meal were employed. In some of the experiments, utilizing purified diets, feather meal served as the sole source of dietary protein. When chicks were fed a simplified corn-feather meal diet, amino acid supplementation markedly improved growth and nitrogen retention. The limiting amino acids in order of importance were lysine, methionine, tryptophan, histidine, and arginine. The growth rate of chicks fed the amino acid supplemented corn-feather meal diet was, however, poorer than

that of control chicks fed a corn-soybean oil meal diet.

In a second type of diet where feather meal, soybean oil meal, and corn each contributed one-third of the protein intake, lysine and methionine supplementation alone produced a maximum growth rate. Since practical poultry rations would seldom contain as much as one-third feather-meal protein, methionine and lysine appear to be the only two amino acids that would require attention in the formulation of poultry rations containing sizable quantities of corn and soybean oil meal protein.

In experiments (*51*) where feather meal is the sole source of dietary protein in purified diets, the amino acid supplementation picture changes. In this diet, the first limiting amino acid for chick growth appears to be histidine. In fact, the data show that the histidine content of the feather is not available to the chick because the chick gives growth responses to graded levels of this amino acid up to and above the total requirement level. In other words, while feather-meal protein contains about 60 percent of the histidine (according to microbiological analysis) needed by the chick, very little of this amino acid appears to be available from the feather protein during digestion.

However, the availability of histidine may not be as poor as indicated above because recent work by Rosenberg, Baldini, and Tollefson (*57*) indicates that the histidine requirement of the chick is greater than previously reported. It is also interesting to note that histidine, lysine, and methionine are concentrated in the less soluble fraction of the original feather (*72*). Methionine, lysine, and tryptophan are, of course, also severely limiting in rations where the only source of protein is feather meal. On the other hand, phenylalanine and arginine supplementation are not effective in improving growth rate.

No combination of amino acid supplements tried allowed maximum growth rate of chicks fed either diets containing feather meal as the only protein source or diets where feather meal and corn were the only protein sources. This means that if it were possible to achieve better growth rates on these diets, certain amino acids like arginine and phenylalanine might be limiting in feather protein. Since some other unrecognized factors limit growth rate on these diets, it is not possible at present to list the amino acid deficiencies of feather protein beyond histidine, lysine, methionine, and tryptophan. Although the data in table 6 indicate that tyrosine (or phenylalanine) is a limiting amino acid when feathers are used to supply all of the protein in the ration of the chick, it has not been possible to demonstrate this deficiency. Presumably this is true because the unrecognized factors that limit growth on diets containing only feather protein are more important to chick growth than the partial deficiency of tyrosine (or phenylalanine).

It is of interest to speculate on the nature of factors that prevent normal growth rate on amino acid supplemented diets containing either feather meal or feather meal and corn as the only sources of protein. If the quantities of amino acids in feather-meal protein (as indicated by microbiological assay) were available to the chick, one would expect the amino acid supplements used in the experiments cited above to allow maximum chick growth rate.

Since it has been shown that the histidine content of feather meal may not be available to the chick, it is entirely possible that other essential amino acids in feather meal are partially unavailable to the chick. Although the microbiological assay indicates the presence of adequate amounts of glycine, leucine, isoleucine, threonine, and valine in feather meal, one or more of these amino acids may be limiting because of the chick's inability to digest and assimilate them from the feather-meal protein. This hypothesis has not yet been tested.

A second possible reason for failure to obtain maximum growth rate on the diets mentioned above would be the presence of inhibitory or toxic principles in feather meal. While this possibility cannot be overlooked, it appears unlikely because it was possible to obtain maximum growth rates with diets containing one-third of their protein from feather meal. If there were a toxic principle in feather meal, it probably would have been expressed in these diets to some degree since they did contain 8 percent of feather meal. The diets that did not permit maximum growth rate contained 12, 16, or 23.6 percent of feather meal. Thus, it is difficult to believe that a toxic substance in feather meal would be expressed to a marked extent at the 12-percent level and not at all at the 8-percent level. At the present time, therefore, the most likely explanation for failure to obtain maximum growth rates on diets heavily dependent on feather-meal protein is poor amino acid availability.

Dietary Nitrogen Retention of Chicks on Diets Containing Feather Meal

The ultimate measure of protein utilization in an experimental animal is the ability of the animal to digest, assimilate, and retain protein or its component amino acids for useful purposes such as growth and reproduction. When the digestibility of a protein is poor, much of the protein is excreted in the feces. When a poorly balanced protein (one that is low in one or more essential amino acids) is fed, many of the amino acids that are digested from the protein and assimilated are excreted in the urine and lost from the body. Thus, both digestibility and amino acid composition are important to efficient protein utilization.

Since nitrogen is an integral part of protein and its component amino acids, the retention of this element by the animal provides a tool by which overall protein digestibility and amino acid availability can be measured in the animal. Nitrogen retention data would, therefore, be of interest as a measure of protein utilization from feather meal.

Naber and Morgan (*50*) reported that dietary nitrogen from rations containing one-quarter of their protein from feather meal was retained by chicks in absolute and relative amounts equal to or greater than that retained by chicks fed the basal ration without feather meal. When total dietary protein intake was a limiting factor, the chicks retained smaller absolute amounts of nitrogen and growth was retarded. The results show that feather-meal protein was digested and utilized as well as the soybean oil meal protein for which it was substituted in the experimental diets.

Experiments using simplified corn-feather meal diets (*51*) showed that properly processed feather meal can be used to supply almost two-thirds of the total dietary protein if lysine, methionine, and tryptophan supplements are used. Under these conditions dietary nitrogen retention is comparable to that shown by chicks fed a corn-soybean oil meal control ration. The findings demonstrate that large quantities of feather-meal protein are well utilized when properly supplemented with limiting amino acids.

Feather Meal as a Source of Unidentified Growth Factors and Vitamins

Since the amino acid composition of feather meal is poor in comparison with fish meal, meat scrap, or soybean oil meal, it seemed strange that feather meal could substitute adequately for these protein supplements, as shown by most of the available data. In fact, several of the previously mentioned reports (*39*, *49*, *50*) indicated that feather meal could replace fish meal and other unidentified growth factor supplements as growth stimulants in corn-soybean oil meal diets. Thus, several research groups began to realize that not all of the nutritive properties of feather meal could be explained on the basis of protein or amino acid composition.

Feathers used for commercial processing of feather meal usually are contaminated with blood and other offal components. In addition, feathers are soaked in water during picking and then allowed to accumulate in containers. During holding prior to processing, considerable fermentation develops in the wet mass. This fermentation could readily add to the growth factor content of the resultant feather meal.

Gregory, Wilder, and Ostby (*27*) have reported microbiological analyses on feather meal for certain vitamins. Five commercial samples were found to contain: 0.68 to 1.34 mg. of riboflavin per pound, 6.12 to 10.43 mg. of niacin, 2.77 to 5.72 mg. of pantothenic acid, and 20.9 to 46.3 mg. of vitamin B_{12} activity. Since feathers are metabolically inactive structural proteins, the vitamin content of the commercial meal probably arises largely from fermentation and contamination of the feathers used.

Menge, Lillie, Sizemore, and Denton (*47*) found that both feather meal and feather-meal ash stimulate chick growth equally when added to a corn-soybean oil meal diet adequately fortified with all known nutrients. The authors postulate the presence of an inorganic growth factor in feather meal. Earlier work (*39*) showed that feather meal could replace fish meal in eliciting growth response on a corn-soybean oil meal ration highly fortified with known nutrients. This finding was also interpreted to mean that feather meal contains unidentified growth-factor activity.

Other workers (*49*, *50*) showed that when feather meal replaced 5 percent of the protein in a broiler diet, including the protein from 2 percent of fish meal and 2 percent of dried whey product, chick growth was equal to that obtained when fish and whey were used. Growth was depressed when the feather meal or the fish-whey combination was omitted from the ration. Again it was suggested that feather meal supplies unidentified factors found in fish meal and whey. In addition, it was demonstrated that feather meal and vitamin B_{12} stimulate growth equally when added to a vitamin B_{12}-deficient assay diet. A combination of vitamin B_{12} and feather meal was not superior to these two supplements used alone. It appeared, therefore, that feather meal supplied vitamin B_{12} in amounts adequate for maximum growth on this assay diet.

During the past few years, other workers (*21*, *32*) have suggested that feather meal contains unidentified nutrient factors for the chick and breeding hen.

Recent work (*51*) has shown that commercially prepared feather meal elicited growth responses on corn-soybean oil meal diets, whereas laboratory samples prepared from clean feathers did not give growth increases. This finding is not surprising if, as noted previously, feather fermentation accounts for nutritive qualities not found in clean feather. It appears, therefore, that most research with commercial feather meal as a protein supplement is complicated by the fact that most commercial samples contain vitamins and unidentified factors. Thus, a growth response from addition of commercial feather meal to a corn-soybean oil meal diet is more likely due to nonprotein nutrients than to protein. Moreover, the evidence indicates that immediate processing of feather wastes from slaughter plants may not be desirable, since such feathers do not have time to ferment. This view is substantiated by chick-growth studies (*51*), which have shown that samples of fermented feather meal gave somewhat better results than the same samples processed without opportunity for fermentation.

Nutritive Value of Feather Meal as Related to Processing Conditions

Since native feather protein is very poorly digestible, it is important that processing methods be carefully evaluated. Obviously, processing conditions should be chosen that yield a meal of maximum digestibility consistent with low amino acid destruction. Several attempts have been made to study the nutritive value of commercial and laboratory samples of feather meal processed under different physical or chemical conditions.

Commercial Samples of Feather Meal

Sullivan and Stephenson (*66*) fed feather-meal samples prepared under several conditions of steam pressure cooking. When samples were fed to chicks at 2.5, 5.0, and 7.5 percent of the diet, no differences in growth rate attributable to processing method were found. This finding is difficult to explain because one of the samples tested consisted of dried ground feathers without steam pressure treatment. It was expected that the dried feathers would be poorly utilized. If this were true and the protein content of the basal diet was barely sufficient for optimum growth, a growth depression would be expected from the untreated feathers. Since this did not occur, it is of interest to speculate on the reasons for the failure to distinguish between the processed and unprocessed samples. One reason suggested above is that the protein content of the experimental diet was not a limiting factor. Thus, it may have been possible to substitute feather meal and corn for soybean oil meal and not produce a diet limiting in protein, in spite of the fact that the feather protein may have been poorly digestible. A second possible reason for the failure to distinguish between the feather meals may be that the range of processing treatments did not greatly affect digestibility of the feather keratin.

Naber, Touchburn, Barnett, and Morgan (*51*) have studied laboratory and commercial samples of feather meal. Seven commercially processed feather meals were tested in corn-soybean oil meal diets as a substitute for one-quarter of the total protein content. One of the samples produced a significant growth depression, while the other six allowed growth comparable to that shown by the corn-soybean oil meal control diet. No detailed data on the methods of processing these samples were available; however, the results show that commercial processing methods do produce significant variations in the nutritive value of feather meal. Nitrogen retention data from the chicks fed the seven samples show that dietary protein utilization was good and not a limiting factor that would explain the poor growth performance attributable to the one commercial sample. Since there was a tendency toward better results from three of the samples, which had been fermented prior to steam processing, it is possible that the nonprotein factors in most commercial feather meals play an important part in their variability.

Laboratory Samples of Feather Meal

To avoid complications associated with meals made from feathers that were fermented or contaminated with nonfeather wastes, it was considered desirable to study the effects of experimental processing on meals produced in the laboratory from clean, unfermented feathers. Thus, samples (described in part I) were prepared for amino acid analyses and feeding tests by the Western Utilization Research and Development Division of the U.S. Department of Agriculture.

The results of experiments (*51*) to evaluate the laboratory feather-meal samples are shown in table 7. An attempt was made to study the usefulness of experimental samples in three types of diets. The first diet provided a total of 21 percent of protein with feather meal, soybean oil meal, and corn, each contributing about one-third of the protein mixture. By use of this ration fortified with methionine and lysine, it was possible to distinguish between a meal made from untreated feathers and six other meals made from feathers treated under a variety of steam pressures for varying lengths of time. The untreated meal, which depressed growth rate, contained 16 percent of pepsin-digestible protein. The treated meals, all of which allowed normal growth, contained from 64 to 83 percent of pepsin-hydrochloric acid digestible protein.

The second experimental diet contained a total of 20 percent of protein with feather meal providing six-tenths and corn the remainder. Methionine, lysine, and tryptophan supplements were used to provide a reasonable amount of growth. When the experimentally processed pure feathers were fed as components of this diet, it was possible to distinguish between the meal made from untreated feathers and the six treated meals. Again, however, it was not possible to distinguish between any of the treated meals.

It is interesting to note that the untreated feathers were utilized to a small degree, in spite of the fact that poor growth resulted from their use. This is deduced from the finding that chicks fed cellulose—substituted in one of the experimental diets for feather meal—gave poorer growth rates than the group fed the diet containing untreated feather meal. The nitrogen retention data for this experiment show that a smaller amount of total nitrogen in the diet of chicks fed the untreated feathers was retained when compared to those fed the six treated samples. Thus, with six-tenths of the dietary protein from feathers,

TABLE 7.—*Effect of feather-meal processing conditions on dietary utilization of protein as measured by growth, feed conversion, and nitrogen retention of chicks at 4 weeks of age* [1]

Source of experimental protein	Processing conditions		Protein digestibility	Experimental ration 1 [2]	
	Time	Pressure		Average body weight	Feed per gram of gain
		P.s.i.	*Percent*	*Grams*	*Grams*
Soybean oil meal				379	1. 64
None [5]					
Experimental feather meal	0	0	16	285	1. 88
	16 hours	12. 5	70	370	1. 63
	30 minutes	30	64	366	1. 54
	90 minutes	30	71	348	1. 64
	4 hours	30	83	347	1. 62
	20 minutes	60	72	339	1. 57
	6 minutes	90	74	338	1. 64
Commercial feather meal					

Source of experimental protein	Experimental ration 2 [3]			Experimental ration 3 [4]	
	Average body weight	Feed per gram of gain	Dietary nitrogen retained	Average body weight	Feed per gram of gain
	Grams	*Grams*	*Percent*	*Grams*	*Grams*
Soybean oil meal	372	2. 17	50	436	1. 59
None [5]	105	3. 34	46		
Experimental feather meal	145	3. 04	33	55	2. 88
	248	2. 48	57	170	2. 15
	252	2. 35	56	131	2. 06
	213	2. 55	55	162	2. 04
	225	2. 48	56	161	2. 05
	222	2. 37	59	171	1. 92
	236	2. 45	45	165	2. 03
Commercial feather meal				269	1. 76
				274	1. 76

[1] Data compiled from a paper by Naber, Touchburn, Barnett, and Morgan (*51*). See text for amino acid supplementation of the 3 diets.

[2] Equal parts protein from corn-soybean meal and experimental source.

[3] 40 percent of protein from corn; 60 percent from experimental source.

[4] All protein from experimental source.

[5] Cellulose substituted.

it was possible to distinguish only between raw ground feather meal and the treated feather meals, with both growth and nitrogen retention as criteria.

The third experimental diet was a 20-percent protein semipurified ration in which all of the protein was supplied by feather meal and crystalline amino acids. Control diets in which soybean oil meal or commercial feather meal was the sole source of intact protein were also employed. The feather-meal-containing diets were supplemented with methionine, lysine, tryptophan, and histidine. It had previously been determined that these four amino acids were needed to promote a moderate growth rate in diets where feather meal was the only protein source. When the experimental feather meals were tested in this third diet, it was possible to determine a treatment difference in the processed meals. Growth of chicks fed the diet containing raw ground feathers was very poor. Chicks fed the diets containing the six processed samples grew at a moderate rate. However, the group of chicks fed the diet containing feather meal processed for 30 minutes under 30 pounds of steam pressure showed a slower growth rate than those fed the other experimentally processed samples. Thus, the sample processed for 30 minutes under 30 pounds of steam pressure (pepsin-hydrochloric acid digestibility equals 64 percent) appeared to be inferior to other treated samples (digestibilities of 70 to 83 percent). Unfortunately, no nitrogen retention data are reported for this experiment. However, the data do suggest that there is some relationship of pepsin-hydrochloric acid digestibility to utilization of feather protein by the growing chick.

The limited data on feather-meal processing and its relation to protein utilization do indicate that the pepsin-hydrochloric acid digestibility of feather meal should be 70 percent or more for adequate utilization by the chick. Growth of chicks fed the third experimental diet containing commercial feather meal was much better than that obtained from laboratory-processed meals made from pure feathers. This fact emphasizes the importance of contamination by nonfeather substances, or fermentation, to the growth-promoting properties of feather meal.

Use of Feather Meal in Livestock Feeds

Feather meal has been accepted widely as a component of poultry feeds. Most research on the use of feather meal in feeds has been done with laboratory rats and chicks. In the past few years, however, interest has developed in its use in rations for swine, sheep, and cattle.

Jordan and Croom (*34*) fed feeder lambs on corn, hay, minerals, and a protein supplement. In some lots more than half of the protein in the supplement was supplied by feather meal. In other lots practically all of the protein in the supplement was furnished by feather meal. Daily gains on these rations were as good as those obtained when the protein supplement was formulated from soybean oil meal and corn. Feather meal did not adversely affect palatability of the protein supplement. Both steam-cooked and lime-processed feather meals were used, and no significant difference between the two types of meal was noted.

Early work with swine (*67*) indicated that feather meal was of no value in rations for swine. However, feather-meal processing was in its infancy during the early 1950's, and possibly a poorly processed product was used. Other experiments (*28*) have shown that daily gains of pigs were not affected when one-third or two-thirds of the soybean oil meal protein in a corn-soybean oil meal meat scrap diet was replaced by feather meal. In addition, no differences were observed when steam-processed feather meal was compared to feather meal processed with addition of lime.

Combs, Alsmeyer, and Wallace (*15*) found that weanling pigs had comparable growth rates when fed either a corn-soybean oil meal ration or a ration in which 5 percent of feather meal replaced about half of the soybean oil meal protein. When 7.5 percent or 10 percent of feather meal was fed to replace three-fourths or all of the soybean oil meal in the basal ration, average daily gains of pigs were reduced. Supplementing the 7.5-percent feather-meal ration with DL-lysine improved gains on this ration. It is apparent from these results that feather meal can be used to replace up to one-half of the soybean oil meal in a 16-percent growing-finishing ration for swine.

The effect of feeding feather meal to beef cattle has been reported by Ray (*55*). Steers were fed lespedeza hay and a grain-protein supplement mixture made from nine parts of corn and either one part of cottonseed meal, one part of feather meal, one part of blood and bonemeal, or one part provided by a combination of the three protein supplements. Average daily gains of the steers were highest when blood and bonemeal or a combination of blood and bonemeal, feather meal, and cottonseed meal was used as the protein supplement. When feather meal or cottonseed meal was used alone, average daily gains were reduced. Digestion coefficients of the four rations were comparable for feather meal, blood and bonemeal, and the combination group, but were lower in the cottonseed meal group. Thus, it appears that neither feather meal nor cottonseed meal used as the sole protein supplement in grain-hay rations for fattening steers will produce gains comparable to blood and bonemeal or a combination of protein supplements. It should be noted that the results with beef cattle are from a single feeding trial.

Feed Formula Design

Feather meal has found a place in many feed formulas. The trend toward use of high-energy rations for poultry and livestock has increased the demand for feedstuffs containing a high percentage of protein. Thus, there has been a trend toward use of high-protein vegetable oil seed meals and high-protein animal byproducts. Feather meal, of course, contains more crude protein than almost any other practical feedstuff. This means that the protein level in a feed formula can be altered with a small amount of feather meal, whereas larger amounts of most other protein feedstuffs would be required. As a result, feather meal allows use of larger amounts of high-energy feedstuffs simply because there is more space left in the formula for energy ingredients when feather meal contributes part of the total protein. Thus, it is possible to increase both the protein and energy level in a feed formula when,

TABLE 8.—*Effect of feather meal substitution on the protein and energy content of a feed formula*

Ingredients in rations	Feed formula	Crude protein in ingredient	Metabolizable energy content of ingredient	Contribution to feed formula	
				Protein	Metabolizable energy
Ration A	*Percent*	*Percent*	*Calories per pound*	*Percent*	*Calories per pound*
Ground yellow corn	60	9	1, 530	5. 40	918
Soybean oil meal	30	44	1, 100	13. 20	330
Minor ingredients	10	20	500	2. 00	50
Total	100			20. 60	1, 298
Ration B					
Ground yellow corn	63	9	1, 530	5. 67	963
Soybean oil meal	24	44	1, 100	10. 56	264
Commercial feather meal	3	[1] 87	[1] 1, 200	2. 61	36
Minor ingredients	10	20	500	2. 00	50
Total	100			20. 84	1, 313

[1] Calculated from average composition data on commercial feather meal, assuming a protein digestibility of 70 percent.

for example, soybean oil meal is partially replaced by feather meal and corn. This point is illustrated in table 8.

Also, when concentrated energy sources like fats become too expensive in relation to their caloric value, use of feather meal to create more room in the formula allows use of less concentrated energy sources like corn without reducing the total caloric value of the ration. These illustrations point out the fact that feather meal gives the nutritionist a means for greater flexibility in feed formulation.

Poultry Meat Scrap, Blood Meal, and Combined Poultry Byproducts

While feather meal has received most of the attention in investigations of the nutritive value of poultry byproducts, poultry meat scrap, blood meal, and combination byproduct meals have been studied by some investigators.

The detailed nutrient composition of poultry offal has been studied by Wisman, Holmes, and Engel (*76*), and Acker, Hartman, Pemberton, and Quinn (*1*). The amino acid analyses show that protein of poultry offal contains much more histidine, isoleucine, lysine, and methionine than does feather-meal protein (*27*). Since feather meal is low in lysine, methionine, and histidine, poultry offal and feather meal together would have a better balanced assortment of amino acids than either of the products alone. However, tryptophan, histidine, and methionine would still limit the usefulness of the offal-feather combination. The ability of these products to furnish the amino acid requirements of the chick is shown in table 4. The pepsin-hydrochloric acid digestibility of poultry offal (*1*) is reported to be 91 percent. This figure is somewhat higher than that reported for well-processed feather meal. However, the data for the nutrient composition of poultry offal were obtained on the raw, uncooked offal (viscera, heads, and feet). It is possible that the dry rendering process used to prepare poultry meat scrap from offal could alter the nutritive value of this product.

Blood meal is a rich source of histidine, lysine, phenylalanine, leucine, and valine (table 6). However, blood meal is poor in arginine, tyrosine, methionine, and isoleucine. Nevertheless, blood protein added to protein from feathers and offal further improves the amino acid pattern in such a mixture. This is illustrated in table 6 by the improved ability of a feather-offal-blood mixture to supply the amino acid requirements of the chick. Note that this mixture in which blood, offal, and feather protein are used in equal amounts satisfied the lysine and histidine needs of the chick. The tyrosine shortage is remedied by an excess of phenylalanine which can be substituted for tyrosine. Thus, methionine and tryptophan are the only limiting amino acids in the three component mixture of proteins.

If poultry-dressing-plant wastes were recombined in their naturally occurring proportions after processing, a meal could be produced which contains protein in the following proportions: 1 part from blood, 4.3 parts from offal, and 8.3 parts from feathers. Such a meal would provide amino acids as indicated in the last column of table 6. The chief advantage of this combination is that it meets the lysine needs of the chick. In feather protein alone, lysine is the first limiting amino acid (*59*). If a single byproduct meal made from feathers, offal, and blood were manufactured from poultry-dressing-plant wastes, it would be a better product from a nutritive point of view than the feather or blood meals used alone.

Feeding tests with poultry meat scrap (*21*, *23*, *49*, *50*, *56*, *77*) have shown that chick growth can be improved when this product is substituted for soybean oil meal protein in a corn-soybean oil meal ration. In most tests poultry meat scrap appears to be a good substitute for some or all of the fish meal, meat scrap, and milk byproducts commonly used in chick starting rations. Poultry meat scrap also appears to be a good dietary source of vitamin B_{12} (*50*). Thus, it appears that poultry meat scrap can be used as a source of unidentified growth factors and vitamin B_{12}. Analytical data on poultry offal (*1*) also reveal that it contains substantial amounts of riboflavin and smaller quantities of other vitamins.

Blood meal has been used in experimental diets successfully (*75*, *77*). In corn-soybean oil meal diets, a combination of blood meal and feather meal stimulated growth and was superior to feather meal alone. A combination of blood meal, poultry meat scrap, and feather meal stimulated growth of broilers and produced results as good as those produced by a combination of fish meal and meat scrap. There appears to be little doubt that blood meal improves the protein quality of feather-meal-containing rations for chickens.

A poultry byproduct meal that recombines blood, offal, and feathers in their naturally occurring proportions has been produced on a pilot-plant basis and experimentally fed to growing chickens. The results (*51*) show that the combination product stimulates chick growth on a corn-soybean oil meal ration and gives results superior to those obtained from feather meal supplementation. Nitrogen retention of chicks fed the ration containing combined byproduct meal was good and comparable to the control ration. Amino acid supplementation of a simplified corn and combined poultry byproduct meal diet (*51*) has shown that growth on this diet can be improved by lysine or a combination of lysine, tryptophan, and histidine. Addition of methionine, on the other hand, depressed growth. Thus it appears that diets containing only combined poultry byproduct meal and corn as protein sources are deficient in lysine and tryptophan or histidine. This finding is not entirely consistent with the amino acid composition data for this product.

Conclusions

Poultry byproducts can be successfully utilized in animal feeds. Experimental feeding primarily with growing chicks has pointed out the assets and limitations of these byproducts.

Properly processed feather meal can be used to supply up to one-quarter of the crude protein in chick starting rations containing large amounts of protein from soybean oil meal and corn. Under these conditions growth is good, amino acid balance is not upset, and dietary nitrogen utilization is not impaired. However, when feather meal is used to supply one-third or more of the total dietary protein, amino acid deficiency problems arise. In experimental diets where corn, soybean oil meal, and feather meal each contributes one-third of the crude protein, supplementation with lysine and methionine is required to restore maximum growth rate. When one-half or more of the protein is contributed by feather meal, the amino acid deficiencies extend to tryptophan, histidine, arginine, and perhaps other amino acids. Feather meal cannot be used indiscriminately as a protein source and calculations of amino acid composition are in order for all feed formulas utilizing this ingredient. Feather meal has also been shown to contain vitamin B_{12} and unidentified growth factors.

Feather meal can be used as a dietary source of protein for swine, sheep, and beef cattle, although more work needs to be done with these animals to establish the usefulness and limitation of this feedstuff.

Processing of feathers should employ conditions of temperature and steam pressure that will result in a meal containing 70 percent or more of pepsin-hydrochloric acid digestible protein.

Poultry meat scrap and blood meal have been studied to a limited degree. These products exhibit better amino acid balance and seem to give slightly better results when compared to feather meal at identical protein levels in rations composed of the same basic ingredients. Poultry meat scrap contains significant amounts of calcium, phosphorus, riboflavin, vitamin B_{12}, and unidentified growth factors.

A combined poultry byproducts meal employing separate or prior processing for the feather component shows better amino acid balance and can be used with fewer limitations than feather meal or blood meal.

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APPENDIX

Determination of Pepsin-Hydrochloric Acid Digestibility

The pepsin-HCl digestibility of feather meal samples was determined by the following simplified procedure:

One-gram samples were weighed into glass-stoppered, 125-ml. flat-bottomed boiling flasks. Fifty milliliters of a freshly prepared solution of 0.20 percent USP pepsin in 0.1*N* hydrochloric acid was added, and the stoppered flasks were mounted on a reciprocating shaker in a 37° ± 1° C. forced-draft incubator. The flasks were shaken constantly for 24 hours. The solid particles hung upon the sides of the flasks were carefully policed down into the solution and the incubation was continued without shaking for another 24 hours.

The contents of the flasks were quantitatively transferred to 100-ml. beakers and brought to pH 6.5 to 7.0 with 1*N* NaOH over a period of at least 10 minutes. The neutral suspensions were then filtered on vacuum through previously prepared, tared Gooch (No. 3) crucibles containing first a layer of medium asbestos and then 1.5 grams of Celite filter aid. The crucible contents were washed three times with warm water, once with 95 percent ethanol, and dried to constant weight at 105° C. The weight gained by the crucible was substracted from the original sample weight to find the proportion digested.

Since this work was done, the Association of Official Agricultural Chemists has adopted a somewhat more elaborate but also more widely applicable method (*19*). The end-over-end agitation and shorter incubation time at higher temperature would seem advantageous but no comparison was made of the methods.

Quantitative Paper Chromatography of Amino Acids[3]

The system of quantitative paper chromatography of amino acids used for this work is based largely on the buffered paper systems investigated by McFarren (*44*). However, only one of the five systems used is among those recommended by McFarren or McFarren and Mills (*45*). The other systems were selected from among the large number for which McFarren supplied data (*44*) with modifications suggested by the work of Krishnamurthy and Swaminathan (*38*) and of Baker and Kahn (*5*). Other modifications were introduced as found desirable or necessary from our own experience, so that the complete system differs considerably from those previously available. Some of the modifications resulted from the necessity for separating small amounts of certain amino acids, such as histidine and methionine, from comparatively large amounts of others. The desirability of keeping the number of systems used to the minimum required for a complete analysis, the sharpness of separations, and other considerations were all factors contributing to the development of this system.

Only the essentials of the system are given here. More detailed information is available in the references noted above and in such books as that by Block, Durrum, and Zweig (*9*).

Chromatographic Equipment

The chromatographic chambers were rectangular glass jars 8 by 12 by 21 inches high with tight-fitting glass covers. The covers were drilled with two holes to permit the addition of solvent after equilibration and the holes in turn were covered by greased microscope slides. Near the top of the jars, a stainless-steel rack supported two glass troughs and four antisiphon rods (Micro-Chemical Specialties, Berkeley, Calif.). Six of these jars were kept in use in a large, well-insulated, top-opening cabinet (previously used for dry-ice storage). The jars were used with different solvent systems so that it was necessary that they be kept tightly closed except as required for operations. The cabinet was adequate for prevention of temperature fluctuations during runs, which appears to be more important than the maintenance of a particular temperature.

The chromatograms were dried and the ninhydrin colors were developed in a forced-draft, stainless-steel-lined oven fitted with a pullout rack from which the papers on glass rods could be suspended (Research Equipment Corp., Oakland, Calif.). It was necessary to line the front and

[3] Use of trade names of specific materials or equipment in this report does not imply a recommendation by the U.S. Department of Agriculture over similar materials not mentioned.

back of the oven with plastic laminate (Formica) to prevent metallic contamination of pH 1 papers. Other somewhat specialized items were a glass sprayer for ninhydrin solutions, stainless-steel scissors, forceps and pinking shears, a supply of stainless-steel clips, and micropipets.

General Procedures

Preparation of buffers:

Stock solutions	*Buffers*
(A) 0.067 N NaOH	pH 1—50 ml. C plus 97 ml. B
(B) 0.20 N HCl	pH 4—154.2 ml. E plus 129.2 ml. F
(C) 0.20 M KCl	pH 8.4—100 ml. D plus 100 ml. G plus 17.1 ml. A
(D) 0.067 M KCl	pH 12—100 ml. E plus 100 ml. A
(E) 0.067 M Na_2HPO_3	
(F) 0.067 M citric acid	
(G) 0.067 M boric acid	

Preparation of Buffered Papers

Two sheets 8 by 22½ inches were cut from 18¼ by 22½-inch sheets of Whatman No. 1 filter paper. One end of each sheet was clipped to a glass rod and the sheet was pulled through the buffer solution and hung on a rack to drain and dry at room temperature. After drying, the sheets were cut to 20 inches long with pinking shears; the end that had been attached to the rod was removed. This serrated end then became the bottom of the sheet. Except for pH 1 papers, sufficient buffered sheets were prepared for several runs. Stored papers were protected from contamination by polyethylene wrappings. Because the pH 1 papers became brittle within a short time, it was necessary to prepare them shortly before use. It was also found necessary to fold them over the antisiphon rods while still wet with buffer and to protect them from metallic contamination with strips of polyethylene between the clips and paper, both during buffering and later during equilibration.

Preparation of Chambers

The glass chromatography chambers were lined with two sheets (18¼ by 22½ in.) of filter paper with the bottom edges of the sheets at the bottom of the chambers. The aqueous phase obtained from the preparation of the solvent to be used in the chamber was poured into the bottom and allowed to saturate the paper lining and atmosphere. Since the chambers were kept in almost continuous use with the same solvent systems, it was not found necessary or desirable to prepare them anew before each run.

Hydrolysis of Samples

Samples (250 mg.) were refluxed with 250 ml. of 6 *N* HCl for 24 hours in 500-ml. round-bottomed boiling flasks. The solution was reduced to small volume on a rotary vacuum evaporator with a 60° C. water bath, transferred to a 100-ml. pear-shaped flask, and taken to dryness on the same evaporator. Drying was completed and excess HCl removed under vacuum over soda lime and calcium chloride. The hydrolyzate was then brought to 5.0 ml. with 10 percent isopropanal and centrifuged to remove insoluble humin.

The insoluble material was bulky but weighed only about 10 mg. and contained less than 1 percent of the total nitrogen. After washing, no amino acid was detectable in the residue by chromatographing with phenol at pH 12.

Application of Samples

Six spots were applied to each sheet along a line 3½ inches from the top edge. The same micropipet was used, with intermediate rinsing, for all spots in a run. Where necessary, repeated applications were made after drying under infrared lamps.

Preparation of Solvents

Phenol (88 percent, Mallinckrodt Gold Label) was used as received. *m*-Cresol, benzyl alcohol, and *t*-amyl alcohol were redistilled and only the clear, colorless center cut was used. Phenol and *m*-cresol were equilibrated with equal volumes of the appropriate buffer, using the upper aqueous phase in the jars and the lower phase as the migrating solvent. Benzyl alcohol, *t*-amyl alcohol, and water (1 : 1 : 2 by volume) were equilibrated for the system used for the separation of the leucines, using the upper phase as the solvent. As an antioxidant and heavy-metal sequestering agent, 0.1 percent of 8-quinolinol was used in all solvents although its effect was slight.

Development of Chromatograms

The spotted sheets (four per chamber) were folded over antisiphon rods at 2¼ inches from the top edge, clipped on, and hung in the chambers. After 2½ to 3 hours' equilibration, the solvents were added to the troughs and the clips removed. At the end of the run, the clips were replaced and the short portion dipping into the trough was cut off to prevent solvent from dripping on the chromatogram. The sheets were then dried at 60° C. for 30 minutes, except for *m*-cresol which was dried for 1 hour.

Ninhydrin Solutions

Stock solution.—One liter of *n*-butanol and 500 ml. of water were equilibrated in a separatory funnel and the lower aqueous layer was discarded. Ten grams of ninhydrin and 1.5 g. of hydrindantin dissolved in acetone equal to 90 percent of the volume of the water-saturated *n*-butanol was

added, followed by 100 ml. of dry *n*-butanol and water equal to 10 percent of the original *n*-butanol phase.

Ninhydrin Reagent No. 1: Stock solution.

Ninhydrin Reagent No. 2: Stock solution plus 4 percent glacial acetic acid.

Ninhydrin Reagent No. 3: Stock solution plus 2 percent triethylamine.

Reagents Nos. 1 and 2 appeared reasonably stable under refrigeration.

Reagent No. 3 turned dark within a short time, so that it was necessary to add the triethylamine just before use.

Application of Ninhydrin Reagent and Development of Color

The dried chromatograms were suspended in a hood before a dark background and sprayed with the appropriate ninhydrin reagent. A simple glass aspirator-type sprayer was found most satisfactory. The reagent was sprayed carefully so that the paper was just saturated. Streaking of the spots occurred if the chromatograms were dipped or if the reagent ran on the paper during spraying.

Elution and Determination of Color

Because the ideal of clearly separated spots is seldom achieved, considerable care and a certain amount of judgment were required in excising the spots from the chromatograms. Incompletely separated spots were cut as closely as could be determined by eye, along the line of minimum color density between them. This requires the assumption that loss of amino acid color is compensated by color from the neighboring spot. The errors involved in such separations probably account for a good part of the total experimental error.

The excised spots were cut in strips (ca. 3/8 by 1 inch) and dropped into colorimetrically matched test tubes. Seven milliliters of 75 percent ethanol was added to each tube with the aid of a pipetting machine and the color extracted for at least 30 minutes with intermittent shaking. After removal of the extracted papers, the colors were read in a colorimeter with a 570 mμ filter (Coleman Model II Universal Spectrophotometer). Proline spots were read with both 570 mμ and 440 mμ filters.

Calculations

Variations of color yield among runs and departures from Beer's law led to adoption of the following method for calculating results:

Each standard and each unknown was replicated four to six times in each run. Mixed standards were prepared for each system with the concentrations of amino acids closely approximating those expected in the unknown and were applied to the strips at only one level. The percentage transmittance of the standard was plotted on the logarithmic scale and the concentration on the linear scale of semilog graph paper. The concentration of the unknown was then read from a straight line drawn from the origin (100 percent transmission) through the standard point. Since proline did not separate cleanly, the color was read at 570 mμ for blue as well as at 440 mμ for yellow, and a correction applied for the blue contaminant. Results can also be calculated from Beer's law since the method assumes that departure from the law is negligible in the immediate vicinity of the standard point.

The advantages of this procedure are that the number of standards necessary is kept at a minimum and that the standards and unknowns are subjected to the same conditions of time, temperature, humidity, and other environmental factors which may affect the colors. The disadvantage, of course, is the need for approximately matching the concentration of the standard to that of the unknown.

The comparisons of unknowns to similarly treated standards permit greater flexibility of scheduling than would ordinarily be possible. For instance, running time can be decreased or increased somewhat as convenient. Also, the papers can be wrapped in polyethylene after development of the colors and held overnight in the dark or, after removal of papers, the solutions of the extracted colors can likewise be held for reading at a more convenient time, but only after papers have been removed.

Individual Systems

Phenol—pH 12: aspartic acid, glutamic acid, serine, glycine, threonine, alanine: 20–24-hour run; No. 2 ninhydrin. Aspartic and glutamic acids from hydrolyzates tend to overlap. If the phenolic solvent remains cloudy, it may be cleared by adding 88 percent phenol a drop at a time.

Phenol—pH 1: lanthionine, cystine, valine; 18- to 22-hour run; No. 3 ninhydrin. Lanthionine and cystine tend to overlap. Tyrosine and phenylalanine also separate.

m-Cresol—pH 4: tyrosine, methionine, phenylalanine; 24-hour run; No. 1 ninhydrin.

m-Cresol—pH 8.4: histidine, arginine, lysine; 40-hour run; No. 2 ninhydrin. The basic amino acids are first separated from the hydrolyzed sample as follows:

After the sample has been hydrolyzed and taken to dryness as previously described, it is taken up in 15 ml. of water. Fifteen milliliters of Amberlite CG–50 Type I resin buffered at pH 5 with sodium acetate is washed into an 8-mm. column and followed by 100 ml. of water. The sample is then washed on to the column and followed by 150 ml. of water. At this point, the basic amino

acids are on the column and the other amino acids have been washed through.

The basic amino acids are eluted with 100 ml. of 1.V HCl, taken to dryness under vacuum, and brought to 5.0 ml. with 10-percent isopropanol. This fraction contains a considerable amount of NaCl so that the spots tend to streak. However, the separations are usually adequate.

Benzyl alcohol; *t*-amyl alcohol; water: proline, leucine, isoleucine; 96-hour run; No. 2 ninhydrin. Valine, tyrosine, and phenylalanine also separate; however, it is necessary to include a part of the valine in the proline spot so that both amino acids cannot be determined on the same chromatogram. The following tabulation gives the amounts of each amino acid per spot determined for this work and the estimated range of amounts that can be used. The lower limits are the amounts giving barely adequate amounts of color for the instrument used. The upper limits are largely dependent upon how well the spots are separated and will thus vary widely according to the composition of the mixture being analyzed.

	Amount used (Gamma)	*Useful range (Gamma)*
Phenol—pH 1:		
Lanthionine	7. 5	5–10
Cystine	20. 0	10–20
Valine	21. 0	3–25
m-Cresol—pH 4:		
Tyrosine	22. 5	15–40
Methionine	4. 0	4–12
Phenylalanine	7. 8	10–50
m-Cresol—pH 8.4 (basic fraction):		
Histidine	5. 5	5–25
Arginine	30. 0	10–50
Lysine	8. 5	5–20
Phenol—pH 12:		
Aspartic Acid	6. 6	4–12
Glutamic Acid	8. 2	3–10
Serine	11. 6	3–15
Glycine	7. 0	3–15
Threonine	5. 0	3–15
Alanine	4. 4	3–15
Benzyl alcohol, *t*-amyl alcohol, water:		
Proline	50. 0	25–75
Isoleucine	6. 0	3–10
Leucine	7. 5	3–10

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